Journal of Bioeconomics (2019) 21:123–144
https://doi.org/10.1007/s10818-018-09282-w

A critical human group size and firm size distributions in industries

Christian Cordes[1] · **Tong-Yaa Su**[1] · **Pontus Strimling**[2]

Abstract

Initially taking a theoretical stance, this paper relates firm-level processes and size distributions of firms at the industry level. An analytically tractable model explores how firm growth, exit, and spinoff activity in combination with systematically appearing growth crises in organizational development translate into specific firm size distributions (FSDs). Based on anthropological, social-psychological, and economic evidence on the effects of increasing group size on performance, the model features a critical organizational size that triggers growth crises. These processes generate size distributions of firms including different right-skewed distributions observed in the empirical literature and self-reinforcing spinoff processes that affect an industry's FSD.

Keywords Firm growth · Critical group size · Firm size distributions · Industry evolution

JEL L11 · D21 · C61

1 Introduction

The distribution of firms by size is an interesting empirical phenomenon to be explained by economists and an important aspect of industrial structures and dynamics (see, e.g.,

---

✉ Christian Cordes
c.cordes@uni-bremen.de

✉ Tong-Yaa Su
tong-yaa.su@uni-bremen.de

Pontus Strimling
pontusstrimling@gmail.se

[1] Faculty of Business Studies and Economics, University of Bremen,
Hochschulring 4, 28359 Bremen, Germany

[2] Institute for Future Studies, Stockholm and Centre for Studies of Cultural Evolution,
Stockholm University, Stockholm, Sweden

Hart and Prais 1956; Simon and Bonini 1958; Mansfield 1962; Ijiri and Simon 1974; Sutton 1997; de Wit 2005; Axtell 2016). In fact, it is one of the most fundamental stylized facts in industrial economics (for a comprehensive survey of the relevant literature see Coad 2009). In addition, there is a long-standing interest of scholars in the theory of the firm in the determinants and consequences of various firm-level developments (e.g., Penrose 1959; Ijiri and Simon 1967; Albach et al. 1984; Audretsch and Mahmood 1994; Langlois and Robertson 1995; Langlois 1998; Foss 2000; Witt 2007; Witt and Schwesinger 2013). As the evolution of business organizations moves through typical phases, one observation is that they experience common problems and challenges arising systematically in the course of their development (see Churchill and Lewis 1983; Greiner 1998; Cordes et al. 2010). In this paper, we root existing empirical industry-level observations concerning firm size distributions (FSDs) in behavioral reality at the firm level affecting organizational development.

For this purpose, we assume a critical organizational size to exist in firm development that systematically induces growth crises. In order to substantiate this claim, we draw on interdisciplinary insights from evolutionary anthropology, social psychology, and economics. A good deal of research in these disciplines has been done on the effects of increasing group size (e.g., Olson 1994; Levine and Moreland 1998; Ostrom 2000; Mukhopadhaya 2003; Spoor and Kelly 2004; Marlowe 2005; Forsyth 2006). While people find it easy and natural to function prosocially in small groups, problems, such as free-riding, bickering, coordination failures, and misbehavior, arise when group size increases: due to this cognitive constraint on human behavior in groups, firm organizations undergo a growth crisis. As shown, the presence of a critical firm size explains several interesting features of an industry's FSD.

Based on these behavioral regularities at the firm level, the proposed analytical model produces several empirically well-established shapes of FSDs. It captures firm dynamics involving patterns of growth and exit of incumbent firms as well as entry of new firms via spinoffs. The cumulated results of these firm dynamics give rise to specific steady-state FSDs including several right-skewed distributions as well as self-reinforcing spinoff dynamics that affect an industry's FSD. In this context, our theoretical concept accounts for a broader range of dynamic processes at the firm level as compared to existing avenues. Moreover, it relates these to well-established industry FSDs and developments within one parsimonious formal framework.

Early work in the field of FSDs has been done by Gibrat (1931) on the size of French firms in terms of employees and Hart and Prais (1956) with data on UK firms whose empirical evidence led them to the conclusion that firm sizes follow a right-skewed, approximately lognormal distribution (also Cabral and Mata 2003). This kind of distribution is, however, only one possible candidate among several skewed distributions. Other researchers opted for power law distributions for they are – compared to the lognormal distribution – better suited to describe the upper tail of the firm size distribution (see, e.g., Steindl 1965; Ijiri and Simon 1974; Stanley et al. 1995). A crucial problem with this type of distribution is, however, that the empirically observed FSDs are characterized by many more middle-sized firms and fewer very large firms (e.g., Vining 1976; Axtell 2001). The mixed results of these inquiries hint at another problem: regularities in FSDs observed at the aggregate level of one industry may not hold in others or with sectoral disaggregation (e.g., Dosi et al. 1995; Bottazzi et al.

2011). Our model, therefore, suggests several factors including behavioral insights that systematically influence FSD and that may differ across industries or life cycle phases leading to different patterns of size distributions.

The article is organized as follows. Next, Sect. 2 presents evidence from anthropology, social psychology, as well as economics for the existence of a critical group size giving rise to growth crises in firm development. Section 3 introduces an analytically tractable model of organizational development and industry evolution that allows the incorporation of these universal behavioral insights on group behavior and that produces stylized FSDs. Based on this formal analysis, Sect. 4 offers a discussion that shows how different patterns of firm growth, exit, and spinoff activity in combination with a critical organizational size translate into specific steady-state FSDs also found in existing empirical work. Section 5 concludes the paper.

2 On the existence of a critical group and organizational size

Anthropology, social psychology, and economics provide some concrete numbers and observations for the existence of a critical group or organizational size that has deep roots in humans' evolutionary past (e.g., Aronson et al. 2002; Robson and Kaplan 2003; Dunbar 2008; Ostrom 2009). For instance, Marlowe (2005) reviews the group sizes among hunter-gatherers whose way of life most closely resembles those of our Pleistocene ancestors. Based on a sample size of 294 cases, local residential groups (bands) averaged 48 (median 30) people. These local groups are nested within ethno-linguistic groups (tribes), whose sizes average 1749 (sample size 396). The author found no indication of local group sizes depending on resources. Instead, the upper limit on their size is determined by the frequency of bickering, reflecting an increase in free riding and opportunism. Hence, these findings suggest that hunter-gather bands tend to equilibrate at sizes around 50 individuals at the band-level and around 1750 individuals at the tribal-level. There is a human disposition to identify with larger, symbolically marked groups and their norms and institutions. Such groups still depend, however, upon the moral dispositions that help stabilize cooperation in local band-scaled groups as their constituents (see Richerson and Boyd 2005). Both numbers constitute potential thresholds at which organizations face developmental crises and may, therefore, manifest themselves in an industry's (possibly multimodal) FSD.

Similarly, Dunbar (1993, 2008) showed that human social groupings exhibit unique distinct size and structure. Thereby, he draws on insights from different disciplines that indicate the existence of cognitive constraints on our ability to maintain social, personalized relationships at a given level of emotional intensity (also Sawaguchi and Kudo 1990; Zhou et al. 2005). To a great extent, the evolution of primate brains was driven by the need to coordinate and manage increasingly large social groups. The finding that average species social group size correlates with relative neocortex size gives several expected critical sizes of human groups, one manifesting at the level of 50 individuals confirming Marlowe's (2005) observation. Human groups based on informal leadership and management by intensive face-to-face contacts and communications, therefore, will tend to equilibrate at similar sizes.

In line with these observations on the existence of a human cognitive constraint on group behavior, studies from economics on village scale commons management suggest that small, band-based systems can work well and be maintained by informal agreements, but that larger systems require formal rules as well as monitoring and sanctions to avoid crisis development (e.g., Ostrom 2000, 2009). Band-sized groups may represent the limits of cooperation organized mainly by informal means in organizations and would thus define the approximate range of a critical firm size. Most firms that significantly exceed this critical size will begin to fashion more formal leadership, rule bound management (including monitoring), and explicit norms and institutions as well as subdivisions to proceed through their growth crisis when they get above a size of 50, if the analogy with bands holds.[1]

Group and firm size affect many aspects of group life and organizational performance. As a group or firm grows larger, many problems appear: members of larger groups tend to be less satisfied with their membership, are absent more often, contribute less often to group activities, are less likely to cooperate with one another, and more likely to behave opportunistically (e.g., Markham et al. 1982; Albanese and van Fleet 1985; Kerr 1989; Levine and Moreland 1990, 1998; Ostrom 2000; Forsyth 2006). A decline in group members' willingness to cooperate with increasing group size is a common phenomenon in social psychology and experimental economics (e.g., Olson 1994; Güth and van Damme 1998; Fehr and Gächter 2000; Spoor and Kelly 2004). Hence, coordination problems and motivation losses are more frequent in larger, more anonymous groups. Moreover, employees who are willing to contribute to the benefit of the organization and who are motivated by a cooperative culture, rather suddenly change behavior when the firm reaches a critical group size (Schelling 1972; Grofman 1974; Gladwell 2000; Card et al. 2008; Cordes et al. 2014). Given this evidence, we assume that in many industries firm organizations systematically undergo a growth crisis in the course of their development (also Churchill and Lewis 1983; Greiner 1998; Cordes et al. 2010) and we expect this observation at the firm level to have repercussions on industry-level FSDs as evidenced with the help of a formal model in the next sections.

On the other hand, bigger organizations may reap the productive potential that larger groups offer beyond the critical group size: for example, a corporation may recover from a growth crisis when organizational restructuring enables further firm growth by keeping its single organizational units below the critical size (e.g., Witt 2000, 2007). Other driving forces of subsequently higher growth rates of larger firms comprise economies of scale (see Jovanovic and MacDonald 1994), the reaching of a critical technological minimum size (see Pratten 1971; Audretsch and Mahmood 1994), success-breeds-success dynamics (e.g., Klepper 1996), or the absence of financial constraints for bigger corporations (e.g., Cabral and Mata 2003). These larger organizations would then feature corporate cultures relying more on formal leadership, hierarchy, and monitoring (see Caliendo et al. 2015).

---

[1] This observation is also given some anecdotal weight by the existence of tailored packages of management services offered by consultancies that aim at firms reaching a critical size at 50 employees. Similarly, in management circles, there has long been a verbal take that firms reach a critical size at approximately this number of employees.

Hence, organizational developments common to all firms due to universal human behavioral dispositions and cognitive constraints might well be stronger determinants of growth than, for example, production-related factors, which differ for companies producing different goods (also Stanley et al. 1996). Given the fundamentals of humans' social psychology operating through the evolution of organizations' cultures, firms should—in the course of their development—systematically face growth constraints and corresponding crises. We expect these growth patterns to lead to specific FSDs.

3 A model of organizational development and industry evolution

In this section, we devise a formal Markov-type model that provides original insights into industry evolution including firm growth, exit, spinoff generation, and aspects of organizational development, such as growth crises that occur due to critical organizational size. Moreover, it is capable of explaining important aspects of stylized facts that emerge from empirical work in the field of FSDs. We therefore combine insights on human behavior in groups at the firm level with industry-level observations.

Our indicator of firm size is employment. Let firm size i ($i = 1, 2, \dots, n$) be the number of employees within a firm, given that there are n different firm sizes in an industry. t ($t = 1, 2, \dots, k$) captures progressing time, while k is the time step in which the equilibrium frequencies of firm sizes are reached. Accordingly, $e_{i,t}$ gives the number of firms with a certain number of employees i at time t. $g_i \in [0; 1]$ captures our Markovian definition of firm growth: it represents the fraction of firms of size i that grows into the next firm size category, $i + 1$. The fraction of firms that exits at each size i is given by $d_i \in [0; 1]$.[2] Firms do not decline. We first derive a recursion that determines the number of firms of size i in the next time step, $e_{i,t+1}$, for $i > 1$, i.e., for the time being excluding firms of the smallest size $i = 1$:

$$e_{i,t+1} = e_{i,t}(1 - d_i)(1 - g_i) + e_{i-1,t}(1 - d_{i-1})g_{i-1}. \quad (1)$$

We can now calculate the equilibrium frequency of firms in size category i in an industry, $\hat{e}_i$, after k iterations. At equilibrium, the number of firms of a certain size i does not change, so that $e_{i,t+1} - e_{i,t} = 0$. Setting $\hat{e}_i = e_{i,t+1} = e_{i,t}$, we obtain for $i > 1$:

$$\hat{e}_i = \frac{e_{i-1,t}(1 - d_{i-1})g_{i-1}}{d_i + g_i - d_i g_i}. \quad (2)$$

In a similar manner, with $i > 2$, we can solve for $\hat{e}_{i-1}$ to get

$$\hat{e}_{i-1} = \frac{e_{i-2,t}(1 - d_{i-2})g_{i-2}}{d_{i-1} + g_{i-1} - d_{i-1}g_{i-1}} \quad (3)$$

---

[2] We assume exiting to take place prior to firm growth processes.

Given Eqs. (2) and (3) and $i > 2$, $\hat{e}_i$ can also be expressed by

$$\hat{e}_i = \frac{e_{i-2,t}(1 - d_{i-2})g_{i-2}(1 - d_{i-1})g_{i-1}}{(d_{i-1} + g_{i-1} - d_{i-1}g_{i-1})(d_i + g_i - d_i g_i)}, \tag{4}$$

which can be simplified so that $\hat{e}_i$ depends on $\hat{e}_1$, the equilibrium frequency of firms of the smallest size $i = 1$:

$$\hat{e}_i = \hat{e}_1 \prod_{j=1}^{i-1} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}}. \tag{5}$$

Proof Eq. (5) is true for $i \geq 3$.

By complete induction, we show that Eq. (5) obtains the correct results for $i \geq 3$. First, we start with the smallest firm size within the range of sizes under consideration here, $i = 3$. In that case, Eq. (5) yields

$$\hat{e}_3 = \hat{e}_1 \frac{(1 - d_1)g_1(1 - d_2)g_2}{(d_2 + g_2 - d_2 g_2)(d_3 + g_3 - d_3 g_3)}, \tag{5a}$$

which is the same result as the one following from Eq. (4). Equation (5), therefore, is true for $i = 3$. Since the equilibrium case is analyzed, $\hat{e}_1 = e_{1,t}$ also holds.

Second, we investigate the case including the largest firm size plus one employee, i.e., $i = n + 1$. In that case, Eq. (5) gives

$$\hat{e}_{n+1} = \hat{e}_1 \prod_{j=1}^{(n+1)-1} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}} = \hat{e}_1 \prod_{j=1}^{n} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}}. \tag{5b}$$

Supposing Eq. (5) is true, we get

$$\hat{e}_n = \hat{e}_1 \prod_{j=1}^{n-1} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}} \tag{5c}$$

by inserting $i = n$. Assuming, in turn, Eq. (5c) is true for n, we show that it is also true for $n + 1$:

$$\begin{aligned}\hat{e}_{n+1} &= \hat{e}_1 \prod_{j=1}^{n-1} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}} \cdot \frac{\left(1 - d_{(n+1)-1}\right)g_{(n+1)-1}}{d_{((n+1)-1)+1} + g_{((n+1)-1)+1} - d_{((n+1)-1)+1}g_{((n+1)-1)+1}} \\ &= \hat{e}_1 \prod_{j=1}^{n-1} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}} \cdot \frac{(1 - d_n)g_n}{d_{n+1} + g_{n+1} - d_{n+1}g_{n+1}} = \hat{e}_1 \prod_{j=1}^{n} \frac{\left(1 - d_j\right)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}},\end{aligned} \tag{5d}$$

which gives us the same result as in (5b). Thus, Eq. (5) is true for $i = n + 1$.

To conclude, Eq. (5) yields the correct results for firm size $i = 3$ and the largest size plus one employee, $i = n + 1$. This implies that Eq. (5) is also true for all other firm sizes, i.e., $i = 4, 5, \ldots, n$. Hence, with the help of this complete induction, we have demonstrated that Eq. (5) holds for $i \geq 3$. ◙

Next, spinoffs are introduced to the model. Let $b_i \in [0; 1]$ be the share of firms of size i that generates a potential spinoff, i.e., an employee considering leaving the firm to start her own business in the same industry. We assume firms of the smallest size $i = 1$ to not generate potential spinoffs. The total number of potential parent firms at equilibrium, measured by $\hat{R}$, is

$$\hat{R} = \sum_{i=2}^{n} \hat{e}_1 \prod_{j=1}^{i-1} \frac{(1 - d_j)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}}. \tag{6}$$

Then, the total number of potential spinoffs at equilibrium, denoted by $\hat{B}$, is expressed by

$$\hat{B} = \sum_{i=2}^{n} b_i \hat{e}_1 \prod_{j=1}^{i-1} \frac{(1 - d_j)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}}. \tag{7}$$

Moreover, B_t gives the number of potential spinoffs and R_t the number of firms in the industry at time t. In addition, we account for other market entrant types, such as startups or diversifying firms originating from other industries: s_1 measures the level of continuous entry activity of this kind. All firms enter at minimum size.

We can now define a recursion that determines the number of firms of the smallest size, $i = 1$, in the next time step, $t + 1$:

$$e_{1,t+1} = e_{1,t}(1 - d_1)(1 - g_1) + s_1 + \delta \frac{B_t}{R_t}. \tag{8}$$

On the rightmost side of this expression, the total number of actually realized spinoffs at time t is given by the term $\delta \frac{B_t}{R_t}$. Within this expression, the ratio $\frac{B_t}{R_t}$ measures the number of potential spinoffs per firm in an industry at time t.[3] Then, parameter δ scales spinoff activity by determining how the spinoff potential per firm translates into real market entry. In this context, δ may vary across regions, cultural environments, or stages of an industry's life cycle.

Setting $\hat{e}_1 = e_{1,t+1} = e_{1,t}$, $\hat{B} = B_t$, and $\hat{R} = R_t$, we obtain for the equilibrium frequency of firms of size $i = 1$:

$$\hat{e}_1 = \hat{e}_1(1 - d_1)(1 - g_1) + s_1 + \delta \frac{\hat{e}_1 \sum_{i=2}^{n} b_i \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}}{\hat{e}_1 \sum_{i=2}^{n} \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}}. \tag{9}$$

---

[3] Using this ratio as an indicator of spinoff intensity in an industry enables us to later derive a much more convenient expression for the steady-state FSD. This approach does not, however, change the qualitative implications of the endogenous generation of spinoffs for industry evolution (see Sect. 3 below).

Solving for $\hat{e}_1$, we have

$$\hat{e}_1 = \left(\delta \frac{\sum_{i=2}^{n} b_i \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}}{\sum_{i=2}^{n} \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}} + s_1 \right) \frac{1}{d_1 + g_1 - d_1 g_1} \tag{10}$$

Given $\hat{e}_1$, we can determine the equilibrium frequency of firms of any size i, $\hat{e}_1$, independent of $\hat{e}_1$. Considering Eqs. (5) and (10), we yield

$$\hat{e}_i = \left(\left(\delta \frac{\sum_{i=2}^{n} b_i \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}}{\sum_{i=2}^{n} \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1}+g_{j+1}-d_{j+1}g_{j+1}}} + s_1 \right) \frac{1}{d_1 + g_1 - d_1 g_1} \right) \prod_{j=1}^{i-1} \frac{(1-d_j)g_j}{d_{j+1} + g_{j+1} - d_{j+1}g_{j+1}}, \tag{11}$$

which gives us the equilibrium number of firms of size i in an industry. Finally, for an equilibrium to exist, the condition $\sum_{i=1}^{\infty} \hat{e}_i d_i = s_1 + \delta \frac{\hat{B}}{\hat{R}}$ must hold, i.e., the inflow of firms has to equal the outflow of firms in equilibrium.[4]

4 Firm-level dynamics and industry-specific firm size distributions

In this Section, we derive some interesting insights from our formal model relating firm-level dynamics and steady-state FSDs at the industry level. It gives insight into what kind of firm dynamics may be underlying specific FSDs including organizational growth crises induced by behavioral regularities in growing groups. Parameters g_i, d_i, and b_i, capturing firm growth, exit, and spinoff generation respectively, proof to be crucial for matching empirically observed FSDs with the model's predictions. We discuss several scenarios to analyze the interplay of these parameters and FSDs.

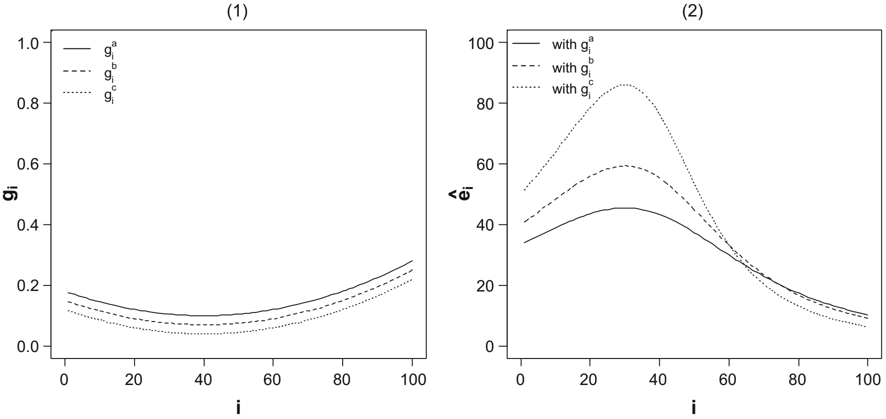
4.1 Growth crises in firm development and right-skewed FSDs

We suggest the fraction of firms growing into the next size category, g_i, to first decline from a relatively high level with growing firm size, then to approach a critical organizational size at which g_i reaches a minimum, and to subsequently increase again due to positive size effects. If we assume such a crisis-induced growth pattern to systematically appear in firm development, we can account for this regularity by defining the share of firms that grows into the next category, g_i, for every observed size class i ($g_i := g(i)$).[5] The simplest form of such a correlation is a stylized U-shaped relation between firm growth and firm size, as shown in Fig. 1. It includes a firm growth crisis around a critical size of 40–50 employees, a number entertained by, for example, anthropological insights on cognitive constraints on human functioning in group

---

[4] The model does not need specific stability devices to impose a steady state as many other models in the field do.

[5] See, for a similar idea, Simon (1955). For the sake of simplicity, we abstract from negative growth rates, i.e., shrinking firm sizes. Below, we will, however, account for certain patterns of firm exit.



Figs. 1 and 2 Asymmetrically shaped relationship between firm growth and size (1) and the corresponding right-skewed FSDs (2) ($d_i = 0.001$, $b_i = 0$, $s_1 = 6$)

contexts. Thus, the behavioral evidence given in Sect. 2 substantiates the concrete definition of the shape of the functional relationship between firm size and growth given in Fig. 1. Moreover, we assume an asymmetric firm-level relationship between growth and size that accounts for the observation that larger corporations have a higher probability to grow into the next size category relative to small ventures. Once firms survive and grow beyond the critical size, they may experience success-breeds-success dynamics and reap size-related advantages that spur growth. Figure 1 also features different levels of growth rates ($g_i^a > g_i^b > g_i^c$). Moreover, in order to isolate firm growth effects on FSDs, there is a constant stream of small new firms entering the industry (measured by s_1),[6] no generation of spinoffs ($b_i = 0$), and a—for the time being—constant exit rate d_i over all size classes.

Given these assumptions, the corresponding FSDs at equilibrium for a certain range of firm sizes produced by the model are presented in Fig. 2 ($\hat{e}_i := \hat{e}(i)$). These distributions become skewed to the right, implying the mass of firm size observations concentrated on the left of the mean and fewer large enterprises in the relatively longer upper tail. In the Appendix, a measure of skewness of these FSDs is given. Therefore, the assumed asymmetric pattern of organizational growth including a crisis in development due to universal cognitive constraints on human behavior in groups translates into right-skewed distributions of firm sizes in the formal model. They resemble lognormal distributions where we observe many middle-sized firms and more small than large enterprises. These theoretical results are in accordance with empirical observations in several industries (e.g., Gibrat 1931; Hart and Prais 1956; Hashemi 2000; Bottazzi and Secci 2003; Cabral and Mata 2003; Reichstein and Jensen 2005; Growiec et al. 2008; Cefis et al. 2009; Gallegati and Palestrini 2010).

Growth dynamics at the firm level generate these specific FSD patterns. The reason for the observation of a relatively high number of firms around the critical size lies in the relationship between g_i, the fraction of firms that grows into the next firm size

---

[6] The model's qualitative results remain unaltered by changing levels of s_1.

class $i + 1$, and g_{i+1}, the fraction of firms leaving this class to grow into $i + 2$. Before an organization reaches the crisis-induced minimum of growth rates, $g_i > g_{i+1}$ holds, i.e., the number of firms entering size class $i + 1$ is greater than the number of firms leaving it. This effect causes firms to amass at sizes where this condition is met. In our model, this phenomenon is salient around the assumed critical firm size and is expected to hold in general for (asymmetric) U-shaped relationships between firm growth and firm size. If, on the other hand, $g_i < g_{i+1}$, more organizations leave size category $i + 1$ than entering it originating from class i. Consequently, the number of firms in class $i + 1$ decreases in this case. Therefore, until reaching the minimum of firm growth rates, the continuously decreasing fraction of firms that grows into the next category causes firm numbers to "pile-up" around these size classes.

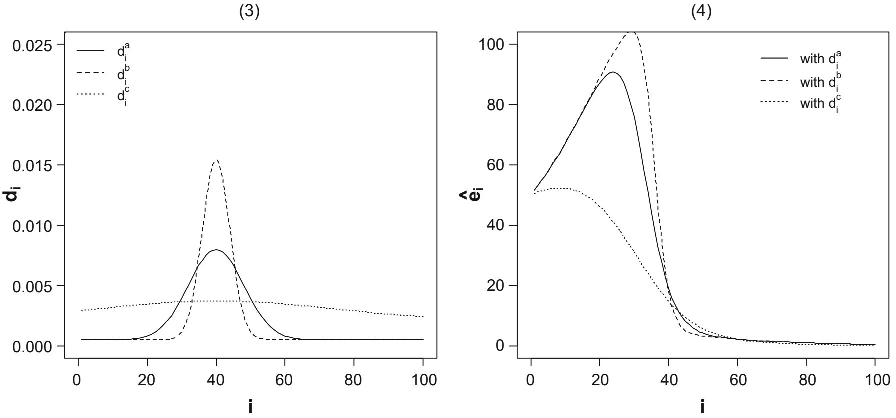
If we expect growth crises due to our cognitive constraint to systematically appear in firm development, they manifest themselves in FSDs as described above irrespective of the other endogenous forces, such as size-related advantages. Hence, our formal model provides a very specific causal mechanism connecting the firm and the industry level. Moreover, when additionally taking into account a critical group size around the tribal level (roughly 1750 individuals, see Sect. 2 for the anthropological evidence) that also systematically induces organizational growth crises, we can also potentially explain bimodal FSDs with a second "piling-up" at these size classes.

Another effect is underlying a—at first view—counterintuitive result: *ceteris paribus*, the lower the level of firm growth rates is ($g_i^a > g_i^b > g_i^c$, see Fig. 1), the disproportionately higher is the number of observed firms around the critical firm size (see corresponding FSDs in Fig. 2). This effect is due to different ratios of firm growth rates between neighboring size categories, $\frac{g_i}{g_{i+1}}$. These vary across g_i^a, g_i^b, and g_i^c: $\frac{g_i}{g_{i+1}}$ is higher, the lower the level of growth rates. For $g_i > g_{i+1}$, i.e., for organizations that have not yet reached the minimum of growth rates, it holds that the higher $\frac{g_i}{g_{i+1}}$, the disproportionately higher is the number of firms that can be observed in class $i + 1$.[7] Accordingly, a relatively lower value of $\frac{g_i}{g_{i+1}}$ implies that relatively more firms grow into the next size class, $i + 2$, preventing firms from amassing at certain size classes to the same extent and rendering the effect of a critical organizational size less pronounced. We then see more large firms active in the industry beyond the point of intersection of the FSDs on the upper tail. The concrete features of crisis-induced growth dynamics at the firm level, therefore, determine the steady-state distribution of organizations over the whole range of size observations.

Moreover, all steady-state FSDs shown in Fig. 2 comprise the same total number of firms active in the industry. This final number of organizations is determined by the steady-state condition, $\sum_{i=1}^{\infty} \hat{e}_i d_i = s_1$ (for $b_i = 0$), where firm entry equals firm exit and the population of firms stops growing. Given the disproportionate amassing of firms around the critical size for different levels of growth rates, this implies that the curves describing the right-skewed FSDs have an intersection at some point on the upper tail of the distribution, beyond which we see different levels of large firm observations (as illustrated in Fig. 2).

---

[7] The opposite holds true beyond the minimum of growth rates: then, the ratio $\frac{g_i}{g_{i+1}}$ is lower, the lower the level of growth rates. In this case, we see a disproportionate decrease in firm numbers. The strength of the "amassing effect" corresponds with the strength of the later decline in size observations.



Figs. 3 and 4 An inverted U-shaped relationship between firm size and exit (3) and the corresponding right-skewed FSDs (4) ($g_i = g_i^c, b_i = 0, S_1 = 6$)

In order to isolate the "piling-up" phenomenon of organizations around the critical organizational size, we assumed firm exit rates to be constant and low over the whole range of size classes ($d_i = 0.001$). However, if there is a naturalistic critical group size around 40–50 individuals, it is reasonable to assume that more firms are going to exit the market when reaching this critical threshold beyond which, *ceteris paribus*, firm performance deteriorates and developmental crisis sets in. This pattern can be captured by an inverted U-shaped relationship between d_i and organizational size with a maximum of firm exit at the critical firm size (for empirical evidence for such an exit pattern see, e.g., Boone et al. 2004). Then, the disproportionate increase in firm numbers around this size changes in shape or may vanish altogether. The resulting FSDs are altered significantly over the whole range of observations. Stylized exit dynamics of this kind are given in Fig. 3 by inverted U-shaped exit patterns that differ in levels of, and variance in, exit rates.[8] The underlying firm growth dynamic is taken from those in Fig. 1 above (g_i^c), i.e., the scenario combines a growth crisis and higher exit rates around the critical organizational size.

Figure 4 shows the right-skewed FSDs generated by these different exit-growth combinations (see Appendix for the calculations of skewness). In the case of two exit patterns, d_i^a and d_i^b, a pronounced peak in firm exit again comes along with a considerable "piling-up" phenomenon of firm size observations in the lower tail of the FSD. This amassing of firm numbers is due to the growth dynamics described above, i.e., as long as $g_i > g_{i+1}$, the number of firms entering class $i + 1$ is greater than the number leaving it. This process is spurred by initially very low exit rates that leave more small firms in the industry. Furthermore, rapidly increasing firm exit induced by the critical organizational size leads to a steep fall in the frequency of firms in following size classes. These exit-growth patterns give rise to the asymmetry

---

[8] For the sake of deriving at clear implications concerning the shape of resulting FSDs, we here choose rather pronounced functional forms for firm exit.

or skewness of the FSDs shown in Fig. 4.[9] We expect this pronounced asymmetry to be observable in industries where a critical organizational size imposes strong constraints on firm development. Finally, an exit pattern characterized by a relatively high level of firm exit over the whole range of size categories, a low increase toward the critical size, and a slight decrease afterwards, as shown by d_i^c, diminishes the "piling-up" of firm observations in certain areas of the FSD by countervailing the growth dynamics explained above. Moreover, depending on the exit patterns' means and variances, we find more or less middle-sized or large firm organizations: for example, the probability to observe relatively large firms in the upper tail of the FSD varies significantly across these exit-growth combinations.

Starting with Gibrat's classic work (1931) on aggregate FSD, much empirical evidence suggests that right-skewed distributions, including the lognormal, are useful approximations describing firm sizes within an industry (also Simon and Bonini 1958; Cabral and Mata 2003; de Wit 2005; Coad 2009). Our theoretical model shows that for reasonable, behaviorally-informed, assumptions on firm-level dynamics, especially as to the existence of a crisis in organizational development, we yield right-skewed FSDs as found in this literature. Particularly in complex, uncertain business environments, this observation should be salient: firms then have to rely on a cooperative corporate culture that depends on the discretionary contributions of highly autonomous members to maintain flexibility of response, coordination, and competitive advantage (see Barney 1986; Gittell 2000; Cooter and Eisenberg 2001; Rob and Zemsky 2002). Since employees' motivation to contribute services of this kind depends on organizational size, firms in industries characterized by such an environment should face such a pronounced critical size where corporate culture changes and developmental crises emerge. Therefore, our considerations concerning expected size distributions lead to the following proposition:

Proposition 1: *If a critical organizational size inducing pronounced growth crises exists in an industry, right-skewed distributions with an amassing phenomenon of firm size observations around this critical size describe the steady-state. Then, the lognormal FSD is a valid heuristic.*

Thus, a cognitive constraint on human behavior in groups taking effect at the level of the individual agent translates into a family of specific, right-skewed FSD at the industry level.

4.2 Selection effects, size-dependent exit rates, and power law FSDs

There are significant differences across industries in the distribution of firm sizes. Especially for data sets including large numbers of smaller firms, researchers have opted for exponential or power law distributions due to their better fit for the upper tail of the FSD (e.g., Steindl 1965; Stanley et al. 1995; Segarra and Teruel 2012). In many industries, small numbers of large firms coexist alongside monotonically increasing numbers of progressively smaller firms (e.g., Axtell 2001, 2016; Dinlersoz

---

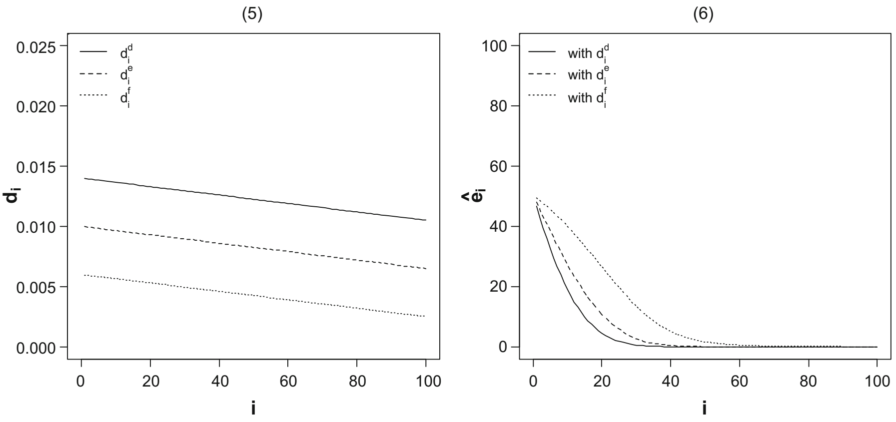
[9] For empirical evidence of such an effect of increasing firm numbers on FSDs see Dinlersoz and MacDonald (2009).

and MacDonald 2009). A lognormal distribution, for example, cannot reproduce such a pattern.

Moreover, the intensity of competition is expected to significantly influence the final steady-state distribution of firm sizes. For instance, an industry that is characterized by a mature business environment allows for investments in expensive capital goods for mass production leading to intensive (price-based) competition among firms. In such a stable setting, larger corporations do relatively better at exploiting existing possibilities, such as refinement, production, and execution, than smaller or middle-sized firms. Instead of relying on a cooperative corporate culture, organizations then employ more formal mechanisms of coordination and control, such as rules, routines, and hierarchical modes of communication, to cope with increasing market selection (e.g., Thompson 1967, p. 71; Crémer 1993). In the course of an industry's life cycle, many business environments are expected to change in this direction: the emergence of a dominant product design (see Utterback and Suárez 1993), an emerging high critical technological firm size (e.g., Audretsch and Mahmood 1994; Jovanovic and MacDonald 1994), or a shift toward process technologies (see Klepper 1997) lead to fiercer competition among firms, favors larger corporations, and lowers the number of organizations growing into higher size classes. In this context, issues of a critical organizational size are expected to be less relevant, for firm cultures would emphasize efficiency and monitoring instead of—size-sensitive—high levels of cooperation. Again, we expect these circumstances to be reflected by specific FSDs in an industry.

Our model shows how the intensity of competition and relative advantages accruing to firm size translate into right-skewed FSDs including larger numbers of small firms and following power law distributions. For this purpose, we capture selection effects on industry-level FSDs by incorporating certain exit dynamics at the firm level: (a) increasing overall competition is reflected by rising levels of firm exit over the whole range of firm sizes and (b) a relative advantage of larger firms leads to a relatively lower likelihood for these ventures to exit the industry (see Axtell 2016). As shown in Fig. 5, the level of competition-induced exit rates, d_i ($d_i := d(i)$), increases step-by-step ($d_i^d > d_i^e > d_i^f$). Within the single levels of exit rates, we assume d_i to decrease with increasing firm size, i.e., small firms exit more often than larger ones ($\frac{\mathrm{d}d_i}{\mathrm{d}i} < 0$; also Sutton 1997). s_1 captures the (constant) level of entry activity. No spinoffs occur ($b_i = 0$). Again, growth rates over size classes, g_i, include a crisis in organizational development because of changing group behavior, as depicted by Fig. 1 (g_i^c).

Figure 6 displays the theoretically predicted development of steady-state FSDs in an industry given a stepwise increase in competition intensity of the kind described above ($\hat{e}_i := \hat{e}(i)$; $\sum_{i=1}^{\infty} \hat{e}_i d_i = s_1$ for $b_i = 0$). The assumed firm-level exit dynamics again generate right-skewed FSDs (see Appendix). Moreover, the fiercer competition becomes, as measured by increasing levels of d_i, the more the stylized shapes of the FSDs resemble power law distributions. Thereby, the total number of firms active in the industry falls as well as the relative likelihood to observe larger firms (also Axtell 2016). We do not see a crisis-induced amassing of firm size observations around certain size classes: the cumulative number of organizations that survive until they reach these categories is too low in this business environment. Klepper (1996, 1997), for example, empirically shows that in many infant industries the initial number of firms is high and



Figs. 5 and 6 The functional relationship between firm exit and firm sizes (5) and right-skewed FSDs as a result of increasing competition (6) ($g_i = g_i^c, b_i = 0, s_1 = 6$)

then experiences a sharp decline in the course of industry development. The shifting curves in Fig. 6 potentially represent the shakeout process taking place in a maturing industry.

Figure 7 shows the shapes of the FSDs depicted in Fig. 6 when plotted using log-log values. The data set includes all observations over the complete range of firm sizes, i.e., no summarizing via histograms, smoothing, tabulating, or truncating has been made. Moreover, the distributions display typical concave shapes, as found in the empirical literature (e.g., Axtell 2001). Using these sets of size observations, ordinary least squares (OLS) regressions have been carried out. The adjusted R^2 values for these OLS estimates inform us about the goodness of fit to a power law distribution. They take on the following values: 0.7911 (for d_i^d), 0.7795 (for d_i^e), and 0.7468 (for d_i^f) ($SD = 0.2898$ for d_i^d; $SD = 0.2119$ for d_i^e; $SD = 0.1297$ for d_i^f). Consequently, these statistics lend significant support to a power law scaling of firm sizes, as has frequently suggested in the empirical literature (e.g., Stanley et al. 1995; Axtell 2001; also Gil and Figueiredo 2013).[10] Our model's pattern of firm growth rates combined with the specific exit dynamics given in Fig. 5 generate FSDs that are well-described by power law distributions.

These considerations are captured by our second proposition concerning another type of right-skewed FSD:

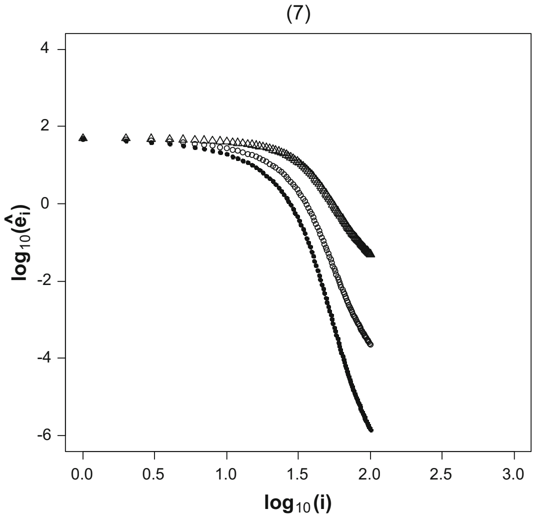
Proposition 2: *Increasing total exit due to growing scale-based competition and exit rates decreasing in firm size lead to right-skewed FSDs in industries well-described by power law distributions.*

Consequently, given an increasing intensity of competition and relative advantages accruing to firm size, the proposed model predicts a development of right-skewed FSDs toward power law distributions, as observed in many empirical studies (e.g.,

---

[10] The data are concave to the origin in these coordinates, reflecting lower numbers of small and large firms in the observations than expected by an ideal power law distribution.

Fig. 7 Log-log plots for the FSDs shown in Fig. 6

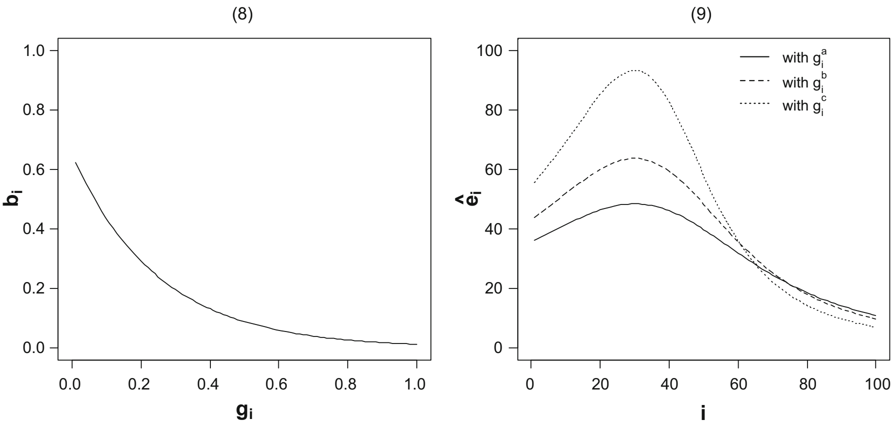


Axtell 2001; de Wit 2005). We expect final FSD of this kind for industries characterized by a stable business environment and accordingly increasingly fierce scale-based competition, where a critical corporate size based on social dispositions of human agents presumably does not play the same role in shaping the FSD as in industries with a more volatile, dynamic business environment that requires more cooperative firm cultures. In this case, the human cognitive constraint on behavior in groups does not show up in the resulting FSDs for it is overlain by competition dynamics.

4.3 Crisis-induced spawning of spinoffs and an industrial "level effect"

If organizations systematically face growth crises at a certain firm size due to agents' cognitive constraints, this potentially leads to the spawning of spinoffs. Some agents will then leave the organization to found their own ventures due to changes in corporate culture and the growth-induced crisis in firm development. With increasing firm size, a cooperative corporate culture is becoming more and more difficult to sustain and the final drop in the level of cooperation is motivating entrepreneurially minded agents to leave the organization. Cordes et al. (2014) present a model of cultural evolution that shows that organizations reaching a critical size experience a collapse of a cooperative culture that triggers the exodus of personnel founding own firms. Garvin (1983) argues that employees start their own firms after becoming frustrated with their employers. Decreasing cooperativeness in the course of firm development as well as a growth crisis are sources of frustration. Hence, a parent firm's evolving corporate culture and systematically appearing growth crises due to behavioral changes are both considered to be triggering mechanisms of spinoffs.

In our FSD model, we account for the systematic generation of spinoffs around a critical organizational size by assuming a certain stylized functional relationship between b_i ($b_i := b(i)$), denoting the share of firms of size i that hosts an employee



Figs. 8 and 9 The stylized relationship between b_i and g_i (8) and FSDs including spinoff generation (9) ($d_i = 0.001$, $s_1 = 6$, δ= 1)

considering founding a spinoff, and g_i ($g_i := g(i)$), capturing patterns of firm growth that include a pronounced growth crisis in organizational development (see again Fig. 1). Figure 8 displays such a stylized relationship between b_i and g_i, where crisis-induced low firm growth rates result in a higher share of firms of a certain size that generate a potential spinoff founder. As shown in Eq. (8) in Sect. 3, the number of actually realized spinoffs, $\delta \frac{B_t}{R_t}$, depends on spinoff intensity and δ, a parameter that scales spinoff activity in a market. δ may vary across industries, institutional set-ups, national cultures, or stages of an industry's life cycle.

Accordingly, Fig. 9 shows the right-skewed steady-state FSDs generated by the model given the additional entry of minimum-sized firms via spinoffs ($\hat{e}_i := \hat{e}(i)$; $\sum_{i=1}^{\infty} \hat{e}_i d_i = s_1 + \delta \frac{\hat{B}}{\hat{R}}$ in the steady state; see the Appendix for the calculation of skewness). If we assume exit rates, denoted by d_i, to be constant over the whole range of observed firm sizes, the total number of firms active in the industry is increasing. Moreover, the additional entry of spinoffs leads to a more than proportional increase in the number of firms active in the market.[11] This effect is due to second and later generation spinoffs that come out of these new firms in the course of their development and that spur the amassing of firm observations on the lower tail of the distribution. The industry, therefore, experiences a "level effect" as to entrepreneurial activity: the crisis-induced exodus of personnel at the firm level initiates a self-reinforcing industry-level process of firm creation that nonlinearly shifts industrial development to a higher level of economic activity (also Garvin 1983; Kenney and von Burg 1999). Due to spinoff activity, we observe more small and middle-sized firms. As a result, we suggest the following proposition:

Proposition 3: *The generation of spinoffs via growth crises in organizational development reshapes right-skewed FSDs by a "level effect" that more than proportionately increases the number of firms active in an industry.*

---

[11] This holds true although FSDs may have intersections on the upper tails of the distributions.

Underlying this “fissioning” process at the industry level is our assumed universal cognitive constraint on the well-functioning of human agents in groups. Via changes in corporate culture, it ultimately triggers spinoffs at the firm level.

Successful industries or regions are driven by such nonlinear dynamics in entrepreneurial activity that are partly based on behavioral regularities at the firm level. High rates of new firm formation are vitally important to their success (e.g., Christensen 1993; Buenstorf and Klepper 2009), at least before a strong shakeout sets in in later stages of the industry’s life cycle (see below). The genealogy of, for instance, Silicon Valley start-up firms shows the importance of such a “fissioning” process based on spinoff activity (see Moore and Davis 2004; Klepper and Sleeper 2005; Klepper 2010). A similar role of spinoffs as the driving-force of industry evolution is shown by Klepper (2002) for the automobile industry, by Kenney and von Burg (1999) for the LAN industry, and by Dahl et al. (2003) for a telecommunication cluster in North-Jutland, Denmark. The shapes of the FSDs generated by our model based on the assumption of growth crisis-induced spinoff activity reflect this implication of self-reinforcing firm entry on industry evolution at a certain stage of its life cycle.

5 Conclusions

We have proposed an analytically tractable model of industry evolution that explored how firm-level processes, such as growth, exit, and spinoff activity, in combination with a critical organizational size translate into specific steady-state firm size distributions (FSDs) at the industry-level. The model generated a set of theoretical predictions that are in line with the existing empirical evidence on right-skewed FSDs including lognormal and power law distributions. Moreover, a level-effect due to crisis-induced and self-reinforcing spinoff dynamics has been shown to modify an industry’s FSD. In this context, our theoretical concept of industry FSDs took into consideration a broader range of dynamic processes at the firm level as compared to existing avenues.

Especially, we accounted for an anthropological constant with deep roots in humans’ evolutionary past: human acting and cooperation in groups works well by more informal means as long as these do not grow beyond band-size. In larger units, various problems including free-riding and motivation losses impair group functioning—they face a cognitive constraint on human behavior in groups. Hence, the fundamentals of humans’ social psychology operate through the evolution of firms. We claimed that the existence of such a critical group size systematically triggers growth crises in organizational development that then manifest themselves in various right-skewed FSD data, for example, through an “amassing phenomenon” of firm size observations around this critical size. Starting from the same setting, we also demonstrated how an increasing competitive intensity in more mature business environments leads to FSDs following power law distributions. By doing so, we delivered new, partly behaviorally-founded, theoretical explanations for some interesting features of empirically observable patterns in FSDs in industries.

Finally, some caveats are in order: first, in its present stage, the model does not allow firms to decline, i.e., there are no negative growth rates. Given our research focus, we assume specific exit patterns to capture the relevant effects, some of which firm decline could also generate. However, in principle it is possible to integrate shrinking firms into the model. Second, employees do not leave their parent firms to join competitors in the same industry. Again, given our research question, we believe this being a minor shortcoming. Finally, a steady-state approach to FSDs can only explain size distributions in industries that are in, or moving toward, a steady-state. In practice, many industries' FSDs may be in an evolving state. Hence, future research should focus on transitional states before the steady-state sets in, a procedure that can be based on an extended version of the proposed model. This avenue will then facilitate the dynamic analysis of some aspects of, for example, an industry's life cycle.

Appendix

Appendix A.1–Appendix A.4 show each of the firm size distributions illustrated in this paper to be skewed to the right. Assuming that variable I denotes firm sizes, we apply

$$Skew(I) = \frac{\hat{M}_3}{\left|\hat{M}_2\right|^{\frac{3}{2}}}$$

in order to obtain the skewness for the entire population in terms of the moments $\hat{M}_2$ and $\hat{M}_3$ (e.g., Fogler and Radcliffe 1974; Hawawini 1980; Doane and Seward 2011). The kth central moment is known as

$$\hat{M}_k = \frac{1}{n}\sum_{j=1}^{n}\left(i_j - \hat{m}_1\right)^k,$$

where n is the amount of realizations of firm sizes I, i_j is the jth realization of I, and $\hat{m}_1$ is the first non-central moment:

$$\hat{m}_1 = \frac{1}{n}\sum_{j=1}^{n}\left(i_j\right)^1.$$

Firm size distributions are skewed to the right, if $Skew(I) > 0$. As opposed to this, firm size distributions are skewed to the left if $Skew(I) < 0$. Firm size distributions are said to be symmetric if $Skew(I) = 0$.

A.1: Firm size distributions (FSDs) in Fig. 2 are skewed to the right.

(a) FSD with g_i^a is skewed to the right: $(Skew(I) = 2.1724) > 0$.
(b) FSD with g_i^b is skewed to the right: $(Skew(I) = 2.3216) > 0$.
(c) FSD with g_i^c is skewed to the right: $(Skew(I) = 2.4243) > 0$.

A.2: Firm size distributions (FSDs) in Fig. 4 are skewed to the right.

(a) FSD with d_i^a is skewed to the right: $(Skew(I) = 1.3963) > 0$.
(b) FSD with d_i^b is skewed to the right: $(Skew(I) = 1.2200) > 0$.
(c) FSD with d_i^c is skewed to the right: $(Skew(I) = 0.9983) > 0$.

◙

A.3: Firm size distributions (FSDs) in Fig. 6 are skewed to the right.

(a) FSD with d_i^d is skewed to the right: $(Skew(I) = 1.0978) > 0$.
(b) FSD with d_i^e is skewed to the right: $(Skew(I) = 1.0318) > 0$.
(c) FSD with d_i^f is skewed to the right: $(Skew(I) = 0.9300) > 0$.

◙

A.4: Firm size distributions (FSDs) in Fig. 9 are skewed to the right.

(a) FSD with g_i^a is skewed to the right: $(Skew(I) = 2.2156) > 0$.
(b) FSD with g_i^b is skewed to the right: $(Skew(I) = 2.3730) > 0$.
(c) FSD with g_i^c is skewed to the right: $(Skew(I) = 2.4980) > 0$.

◙

References

Albach, H., Bock, K., & Warnke, T. (1984). Wachstumskrisen von Unternehmen. *Z Betriebswirt, 36,* 779–793.

Albanese, R., & van Fleet, D. D. (1985). Rational behavior in groups: The free-riding tendency. *The Academy of Management Review, 10,* 244–255.

Aronson, E., Wilson, T. D., & Akert, R. M. (2002). *Social psychology*. Upper Saddle River, NJ: Prentice-Hall.

Audretsch, D. B., & Mahmood, T. (1994). Firm selection and industry evolution: the post-entry performance of new firms. *The Journal of Evolutionary Economics, 4,* 243–260.

Axtell, R. L. (2001). Zipf distribution of U.S. firm sizes. *Science, 293,* 1818–1820.

Axtell, R. L. (2016). 120 Million agents self-organize into 6 million firms: A model of the U.S. Private Sector. In: Thangarajah, J., Tuyls, K., Jonker, C., Marsella, S. (eds.) Proceedings of the 15th International Conference on Autonomous Agents and Multi agent Systems, pp 806–816. Singapore

Barney, J. B. (1986). Organizational culture: can it be a source of sustained competitive advantage? *The Academy of Management Review, 11,* 656–665.

Boone, C., Carroll, G. R., & van Witteloostuijn, A. (2004). Size, differentiation and the performance of Dutch daily newspapers. *Industrial and Corporate Change, 13,* 117–148.

Bottazzi, G., Coad, A., Jacoby, N., & Secci, A. (2011). Corporate growth and industrial dynamics: evidence from French manufacturing. *Applied Economics, 43,* 103–116.

Bottazzi, G., & Secci, A. (2003). Common properties and sectoral specificities in the dynamics of U.S. manufacturing companies. *Review of Industrial Organization, 23,* 217–232.

Buenstorf, G., & Klepper, S. (2009). Heritage and agglomeration: the Akron tyre cluster revisited. *The Economic Journal, 119,* 705–733.

Cabral, L. M. B., & Mata, J. (2003). On the evolution of the firm size distribution: facts and theory. *The American Economic Review, 93,* 1075–1090.

Caliendo, L., Monte, F., & Rossi-Hansberg, E. (2015). The anatomy of French production hierarchies. *JPE, 123,* 809–852.

Card, D., Mas, A., & Rothstein, J. (2008). Tipping and the dynamics of segregation. *Quarterly Journal of Economics, 123,* 177–218.

Cefis, E., Marsili, O., & Schenk, H. (2009). The effects of mergers and acquisitions on the firm size distribution. *Journal of Evolutionary Economics, 19,* 1–20.

Christensen, C. M. (1993). The rigid disk drive industry: a history of commercial and technological turbulence. *The Business History Review, 67,* 531–588.

Churchill, N. C., & Lewis, V. L. (1983). The five stages of small business growth. *Harvard Business Review, 61,* 30–50.

Coad, A. (2009). *The growth of firms: a survey of theories and empirical evidence*. Cheltenham: Edward Elgar.

Cooter, R., & Eisenberg, M. A. (2001). Fairness, character, and efficiency in firms. *The University of Pennsylvania Law Review, 149,* 1717–1733.

Cordes, C., Richerson, P. J., & Schwesinger, G. (2010). How corporate cultures coevolve with the business environment: the case of firm growth crises and industry evolution. *The Journal of Economic Behavior and Organization, 76,* 465–480.

Cordes, C., Richerson, P. J., & Schwesinger, G. (2014). A corporation's culture as an impetus for spinoffs and a driving force of industry evolution. *The Journal of Evolutionary Economics, 24,* 689–712.

Crémer, J. (1993). Corporate culture and shared knowledge. *Industrial and Corporate Change, 2,* 351–386.

Dahl, M. S., Pedersen, C. Ø. R., Dalum, B. (2003). Entry by Spinoff in a High-Tech Cluster. DRUID Working Paper No 03-11:1-33

de Wit, G. (2005). Firm size distributions: an overview of steady-state distributions resulting from firm dynamics models. *International Journal of Industrial Organization, 23,* 423–450.

Dinlersoz, E. M., & MacDonald, G. M. (2009). The industry life-cycle of the size distribution of firms. *Review of Economic Dynamics, 12,* 648–667.

Doane, D. P., & Seward, L. E. (2011). Measuring skewness: A forgotten statistic? *Journal of Statistics Education, 19,* 1–18.

Dosi, G., Marsili, O., Orsenigo, L., & Salvatore, R. (1995). Learning, market selection and the evolution of industrial structures. *Small Business Economics, 7,* 411–436.

Dunbar, R. I. M. (1993). Co-evolution of neocortex size, group size and language in humans. *Behavioral and Brain Sciences, 16,* 681–735.

Dunbar, R. I. M. (2008). Cognitive constraints on the structure and dynamics of social networks. *Group Dynamics-Theory Research And Practice, 12,* 7–16.

Fehr, E., & Gächter, S. (2000). Cooperation and punishment in public goods experiments. *The American Economic Review, 90,* 980–994.

Fogler, R. H., & Radcliffe, R. C. (1974). A note on measurement of skewness. *Journal of Financial and Quantitative Analysis, 9,* 485–489.

Forsyth, D. R. (2006). *Group dynamics*. Belmont: Thomson Wadsworth.

Foss, N. J. (2000). The theory of the firm: an introduction to themes and contributions. In N. J. Foss (Ed.), *The theory of the firm* (pp. 15–61). Routledge, London: Critical perspectives on business and management.

Gallegati, M., & Palestrini, A. (2010). The complex behavior of firms' size dynamics. *The Journal of Economic Behavior and Organization, 75,* 69–76.

Garvin, D. A. (1983). Spin-offs and the new firm formation process. *California Management Review, 25,* 3–20.

Gibrat, R. (1931). *Les inégalités économiques*. Paris: Librairie du Receuil Sirey.

Gil, P. M., & Figueiredo, F. (2013). Firm size distribution under horizontal and vertical innovation. *The Journal of Evolutionary Economics, 23,* 129–161.

Gittell, J. H. (2000). Organizing work to support relational co-crdination. *International Journal of Human Resource Management, 11,* 517–539.

Gladwell, M. (2000). *The tipping point*. Boston: Little, Brown and Company.

Greiner, L. E. (1998). Evolution and revolution as organizations grow. *Harvard Business Review, 76,* 55–67.

Grofman, B. (1974). Helping behavior and group size: some exploratory stochastic models. *Behavioral Sciences, 19,* 219–224.

Growiec, J., Pammolli, F., Riccaboni, M., & Stanley, E. H. (2008). On the size distribution of business firms. *Economics Letters, 98,* 207–212.

Güth, W., & van Damme, E. (1998). Information, strategic behavior, and fairness in ultimatum bargaining: an experimental study. *Journal of Mathematical Psychology, 42,* 227–247.

Hart, P. E., & Prais, S. J. (1956). The analysis of business concentration: a statistical approach. *Journal of the Royal Statistical Society, 119,* 150–191.

Hashemi, F. (2000). An evolutionary model of the size distribution of firms. *The Journal of Evolutionary Economics, 10,* 507–521.

Hawawini, G. A. (1980). An analytical examination of the intervaling effect on skewness and other moments. *Journal of Financial and Quantitative Analysis, 15,* 1121–1127.

Ijiri, Y., & Simon, H. A. (1967). A model of business firm growth. *Econometrica, 35,* 348–355.

Ijiri, Y., & Simon, H. A. (1974). Interpretations of departures from the Pareto curve firm-size distributions. *The Journal of Political Economy, 82,* 315–331.

Jovanovic, B., & MacDonald, G. M. (1994). The life cycle of a competitive industry. *The Journal of Political Economy, 102,* 322–347.

Kenney, M., & von Burg, U. (1999). Technology, entrepreneurship and path dependence: industrial clustering in Silicon Valley and Route 128. *Industrial and Corporate Change, 8,* 67–103.

Kerr, N. L. (1989). Illusions of efficacy: The effects of group size on perceived efficacy in social dilemmas. *The Journal of Experimental Social Psychology, 25,* 287–313.

Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review, 86,* 562–583.

Klepper, S. (1997). Industry life cycles. *Industrial and Corporate Change, 6,* 145–181.

Klepper, S. (2002). The capabilities of new firms and the evolution of the US automobile industry. *Industrial and Corporate Change, 11,* 645–666.

Klepper, S. (2010). The origin and growth of industry clusters: The making of Silicon Valley and Detroit. *The Journal of Urban Economics, 67,* 15–32.

Klepper, S., & Sleeper, S. B. (2005). Entry by spinoffs. *Management Science, 51,* 1291–1306.

Langlois, R. N. (1998). Personal capitalism as charismatic authority: the organizational economics of a Weberian concept. *Industrial and Corporate Change, 7,* 195–213.

Langlois, R. N., & Robertson, P. L. (1995). *Firms, markets and economic change: A dynamic theory of business institutions*. London: Routledge.

Levine, J. M., & Moreland, R. L. (1990). Progress in small group research. *The Annual Review of Psychology, 41,* 585–634.

Levine, J. M., & Moreland, R. L. (1998). Small groups. In D. T. Gilbert, S. T. Fiske, & G. Lindzey (Eds.), *The handbook of social psychology* (pp. 415–469). Boston: McGraw-Hill.

Mansfield, E. (1962). Entry, Gibrat's law, innovation, and the growth of firms. *The American Economic Review, 52,* 1023–1051.

Markham, S. E., Dansereau, F., Jr., & Alutto, J. A. (1982). Group size and absenteeism rates: A longitudinal analysis. *The Academy of Management Journal, 25,* 921–927.

Marlowe, F. W. (2005). Hunter-gatherers and human evolution. *Evolutionary Anthropology, 14,* 54–67.

Moore, G., & Davis, K. (2004). Learning the Silicon Valley way. In T. F. Bresnahan & A. Gambardella (Eds.), *Building high-tech clusters: Silicon Valley and beyond* (pp. 7–39). Cambridge: Cambridge University Press.

Mukhopadhaya, K. (2003). Jury size and the free rider problem. *Journal of Law Economics and Organization, 19,* 24–44.

Olson, M. (1994). *The logic of collective action*. Cambridge, MA: Harvard University Press.

Ostrom, E. (2000). Collective action and the evolution of social norms. *The Journal of Economic Perspectives, 14,* 137–158.

Ostrom, E. (2009). A general framework for analyzing the sustainability of social-ecological systems. *Science, 325,* 419–422.

Penrose, E. T. (1959). *The theory of the growth of the firm*. London: Basil Blackwell.

Pratten, C. F. (1971). *Economies of scale in manufacturing industry*. Cambridge: Cambridge University Press.

Reichstein, T., & Jensen, M. B. (2005). Firm size and firm growth rate distributions—the case of Denmark. *Industrial and Corporate Change, 14,* 1145–1166.

Richerson, P. J., & Boyd, R. (2005). *Not by genes alone: how culture transformed human evolution*. Chicago: The University of Chicago Press.

Rob, R., & Zemsky, P. (2002). Social capital, corporate culture, and incentive intensity. *The RAND Journal of Economics, 33,* 243–257.

Robson, A. J., & Kaplan, H. S. (2003). The evolution of human life expectancy and intelligence in hunter-gatherer economies. *The American Economic Review, 93,* 150–169.

Sawaguchi, T., & Kudo, H. (1990). Neocortical development and social structure in Primates. *Primates, 31,* 283–289.

Schelling, T. C. (1972). The process of residential segregation: neighborhood tipping. In A. H. Pascal (Ed.), *Racial discrimination in economic life* (pp. 157–184). Lexington, MA: Lexington Books.

Segarra, A., & Teruel, M. (2012). An appraisal of firm size distribution: does sample size matter? *The Journal of Economic Behavior and Organization, 82,* 314–328.

Simon, H. A. (1955). On a class of skew distribution functions. *Biometrika, 42,* 425–440.

Simon, H. A., & Bonini, C. P. (1958). The size distribution of business firms. *The American Economic Review, 48,* 607–617.

Spoor, J. R., & Kelly, J. R. (2004). The evolutionary significance of affect in groups: Communication and group bonding. *Group Processes & Intergroup Relations, 7,* 398–412.

Stanley, M. H. R., Amaral, L. A. N., Buldyrev, S. V., Havlin, S., Leschhorn, H., Maass, P., et al. (1996). Scaling behavior in the growth of companies. *Nature, 379,* 804–806.

Stanley, M. H. R., Buldyrev, S. V., Havlin, S., Mantegna, R. N., Salinger, M. A., & Stanley, E. H. (1995). Zipf plots and the size distribution of firms. *Economics Letters, 49,* 453–457.

Steindl, J. (1965). *Random processes and the growth of firms*. London: Griffin.

Sutton, J. (1997). Gibrat's legacy. *J Econ Lit, 35,* 40–59.

Thompson, J. D. (1967). *Organizations in action*. New York: McGraw-Hill.

Utterback, J. M., & Suárez, F. F. (1993). Innovation, competition, and industry structure. *Research Policy, 22,* 1–21.

Vining, D. R. (1976). Capacity expansion and its implications for the size distribution of firms: some remarks on a recent paper by L. Hjalmarsson. *The European Economic Review, 7,* 281–285.

Witt, U. (2000). Changing cognitive frames—changing organizational forms: an entrepreneurial theory of organizational development. *Industrial and Corporate Change, 9,* 733–755.

Witt, U. (2007). Firms as realizations of entrepreneurial visions. *Journal of Management Studies, 44,* 1125–1140.

Witt, U., & Schwesinger, G. (2013). Phylogenetic footprints in organizational behavior. *The Journal of Economic Behavior and Organization, 90*(Supplement), S33–S44.

Zhou, W. X., Sornette, D., Hill, R. A., & Dunbar, R. I. M. (2005). Discrete hierarchical organization of social group sizes. *Proceedings Of The Royal Society B-Biological Sciences, 272,* 439–444.