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SUNK COSTS, FIRM SIZE AND FIRM GROWTH*

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For several decades, the conventional wisdom has been that expected firm growth rates are independent of firm size, a property known as Gibrat's Law. However, recent empirical work has found a negative relation between firm growth and firm size.

This paper provides a theoretical explanation for this negative relation in a model of new firm growth where capacity and technology choices involve some degree of sunkness. Additional empirical implications of the theory of sunk costs are also developed. These relate to profit rates, Tobin's Q, exit rates, degree of sunkness of capacity costs, as well as size and growth rates.

I. INTRODUCTION

FOR SEVERAL decades the conventional wisdom has been that expected firm growth rates are independent of firm size, a property known as Gibrat's Law. Mansfield [1962] found a negative relation between size and growth and conjectured that this resulted from sample bias.[1] However, recent empirical work by Evans [1987a,b], Hall [1987], and Dunne, Roberts and Samuelson [1989] has found a negative relation between firm growth and firm size that is not a consequence of sample bias.[2]

This paper provides a theoretical explanation for this negative relation in a model of new firm growth. The idea is that capacity and technology choices involve some degree of sunkness (that is, investments for which value is forgone upon exit). Since small entrants are more likely to exit than are large entrants, it is optimal for small entrants to invest more gradually, and thus experience higher expected growth rates, than do large entrants.

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[1] The idea is that most small firms experiencing negative growth exit the industry and are thus not included in the sample.

[2] Evans and Hall directly correct for sample bias, whereas Dunne, Roberts and Samuelson use group data techniques. All of these authors use US data; similar results were derived from data for Italy (Bianco and Sestito [1993]), the Netherlands (Huigen, Kleijweg and van Leeuwen [1991]), Portugal (Mata [1994]) and the UK (Kumar [1985], and Dunne and Hughes [1994]).

Specifically, we assume that firms must incur a sunk cost in building production capacity.[3] In the first period upon entry, firms build only a fraction of their long-run optimal capacity. This fraction is lower when the firm's expected efficiency is lower, thus implying a negative relation between initial size and expected growth.

The paper proceeds as follows. In Section II we introduce a simple model without sunk costs. We impose an assumption that implies that, absent sunk costs and correcting for sample bias, there would be no relation between size and growth. Then, in the following section, we extend the model by considering the possibility of sunk costs and show that a negative relation between size and growth results. Section IV presents additional empirical implications of our theory of sunk costs. Section V concludes the paper.

II. BASIC MODEL

Our basic model consists of an infinite-period competitive industry characterized by some demand function. In each period, there is a measure of atomistic firms entering the industry. Each of these firms is endowed with a variable cost function $s_t C(q_t/s_t)$, where q_t is quantity and s_t is the firm's efficiency type at age t. Fixed cost, F, is assumed to be the same for all firms. Marginal cost, given by $C'(q_t/s_t)$, is assumed to be an increasing function. Each firm is a price taker; in addition, price is constant in all periods. The idea is that the industry is at a steady state with entry and exit but zero growth. Since we will only look at one generation of firms, time and age will coincide.

Given the way the cost function is defined, each firm's type reflects its efficiency, or productivity: firms of a higher type are more efficient firms. In fact, solving the firm's optimal problem in each period,

$$(1) \qquad \max_q \Pi(q; s_t) = pq - s_t C(q/s_t) - F,$$

yields an optimal output

$$(2) \qquad q^*(s_t) = s_t h(p),$$

where $h(\cdot)$ is the inverse of the marginal cost function, and an optimum profit

$$(3) \qquad \pi(s_t) \equiv \Pi(q^*(s_t); s_t) = s_t\big(ph(p) - C(h(p))\big) - F,$$

an increasing function of efficiency s_t. We normalize units so that $ph(p) - C(h(p)) = 1$. Therefore, optimum variable profit is equal to the

[3] Recent literature has focused on the implications of sunk *entry* costs, which are independent of firm size. See Dixit [1991], Lambson [1991, 1992], and Lippman and Rumelt [1992]. By contrast, we focus on sunk *capacity* costs, which are proportional to total capacity. The main implication of the former is firm hysteresis, whereas, as we will see, the latter have implications for the way in which firms grow.

productivity parameter s_t, which in turn is proportional to optimal output.

As in the models of Jovanovic [1982], Lippman and Rumelt [1982], and Hopenhayn [1992], we assume that firms learn about their efficiency.[4] Specifically, we assume that after one period firms learn the exact value of s_t for $t > 1$, whereas period 1 productivity provides a signal of future productivity.[5]

Given the simple structure of s_t, the timing of each firm's decision is also relatively simple:

1. Pay entry fee;
2. Observe first-period type s_1;
3. Choose to stay or to exit;
4. Choose first-period output q_1; receive first-period payoff;
5. Observe second-period type s_2;
6. Choose second-period output q_2;
7. Choose to stay or to exit; receive second-period payoff;
8. In all periods $t > 2$, firms repeat period 2's decisions.

By placing the second-period output decision before the decision of whether or not to stay in the industry, we implicitly assume that q_2 is period 2 output *conditional on staying in the industry*. Obviously, if the firm exits, then its output is zero. The idea is that we will be interested in expected growth rates including all firms—that is, *not conditional on exit decisions*.[6]

Regarding the distribution of s_t, we assume that

(4) $$s_t \in \{H, M, L\},$$

with $H > M > L$ and a transition matrix A from s_1 to s_2:

(5) $$A = \begin{bmatrix} 1 & 0 & 0 \\ \alpha & \beta & 1 - \alpha - \beta \\ 0 & 0 & 1 \end{bmatrix},$$

where $\alpha + \beta < 1$. The idea of this simple structure is to model an empirical fact for which there is ample evidence: the probability of survival is increasing

[4] This contrasts with models in which firms make investments that affect their productivity in an uncertain way (Ericson and Pakes [1989]) and models in which firms learn about market demand (Lambson [1991, 1992]).

[5] Given this assumption, firms choose the same quantity for all $t > 1$. In this way, the model is consistent with the stylized fact that expected growth rates are decreasing with age for a given cohort of firms.

[6] More formally, we may assume that firms choose q_2 and the value of I, an indicator variable that equals 1 if the firm stays in and 0 if the firm exits. Second period *actual* output is then given by Iq_2. In the terminology of Dunne, Roberts and Samuelson [1989], $(q_2 - q_1)/q_1$ is the *potential* growth rate, while $(Iq_2 - q_1)/q_1$ is the *realized* growth rate.

with initial size.[7] Suppose that the following assumption holds:

Assumption 1. $L < F < H$.

Then, it is optimal for firms with $s_1 = L$ to exit the market (zero survival rate). Firms with $s_1 = H$, in turn, have a 100% probability of survival. Finally, firms with $s_1 = M$ survive with a probability $0 < \alpha + \beta < 1$. Since q_1 is proportional to s_1 (for firms that are active), we conclude that the probability of survival is increasing with initial size.

The positive relation between starting size and survival rates will play a crucial role in our result that when sunk investments are present small firms ought to invest more gradually than large ones.[8]

Before stating our first result, we make one additional assumption.

Assumption 2. $E(s_2 \mid s_1) = s_1$.

This assumption, as the next result shows, implies Gibrat's Law when correcting for the sample bias. Together with Assumption 1, it also implies that the sample bias induces an observed negative relation between size and expected growth.

Lemma 1. (Gibrat's Law) Under Assumptions 1–2, expected growth is independent of size. However, expected growth of *surviving* firms is decreasing with size.

(All proofs may be found in the appendix.) Since we want to find an explanation for the negative relation between size and growth *beyond* that of sample bias, in the remainder of this article we will maintain Assumptions 1–2. In the next section, we will show that, even correcting for the sample bias, a negative relation between size and growth obtains when there are sunk costs.

III. SUNK CAPACITY COSTS

Consider the following extension of the basic model. In addition to the production cost $s_t C(q_t/s_t)$, assume that firms must build capacity at a cost

[7] The matrix A also implies that the variability of growth rates is decreasing with size (cf Evans [1987b]). Moreover, it is consistent with, although it does not imply, the empirical regularity that variability of size among survivors of the same cohort increases with age (Audretsch and Mahmood [1992]).

The simple structure we consider allows us to capture the essential elements of the models with passive efficiency learning (e.g., Jovanovic [1982]) and at the same time keep the analysis simple enough. A more realistic model would feature—as in Jovanovic [1982]—a full support for s_2 for all values of s_1. The main result in this paper would still hold in this context, although the proof would be unnecessarily more complicated. See the remarks after Proposition 1.

[8] As a matter of convention, we will refer to firms with $s_1 = H$ as large firms and firms with $s_1 = M$ as small firms; notice that firms with $s_1 = L$ never become active.

of k per unit. This cost is totally sunk. Investment in capacity can be made in any period.[9]

The timing of the model is now changed in the following way: in each period, before choosing quantity q_t, firms must choose capacity K_t and pay $k(K_t - K_{t-1})$. In terms of the timing structure presented above, this consists of two extra moments: one just before step 4, and the other just before step 6.

The main result of the paper is that, under sunk costs, Gibrat's Law no longer holds.

Proposition 1. If capacity costs are sunk, then small firms grow faster than large firms.

The intuition for the result is quite simple. Large firms have a low probability of exit in future periods. In our model, we consider the extreme case in which this probability is zero. As a result, the optimal choice in the first period is the same as in any future period; that is, large firms invest to their optimal capacity from period 1 on.

Small firms, by contrast, exit with positive probability, and in case of exit the initial investment in capacity is lost. Therefore, it is optimal for these firms to invest less in the first period than the long-run capacity level. In the second period, with positive probability, these firms stay in the industry and adjust capacity to its long-run level, thus experiencing a supra-normal growth rate.[10]

III(i). *Technology choice with sunk costs*

An alternative way of modeling sunk investment costs would be to assume that firms can opt for a *capital-intensive technology*.[11] Assume that the capital-

[9] For simplicity, we assume that there are no costs in adjusting capacity other than capacity costs. Adjustment costs might mitigate the effect described in our main result; however, if they are not very important with respect to sunk costs, the result still holds.

[10] This intuition is also key to understanding that our main result, while based on a very stylized model, is actually robust to different possible generalizations. The critical assumption is that the distribution of s_2 conditional on s_1 be monotone in s_1, in the sense of first-order stochastic dominance. In particular, the probability of exit should be higher when s_1 is lower. This implies that the opportunity cost of investing in the first-period is higher when s_1 is lower. In fact, if δ is the discount factor, the opportunity cost of capacity in the first period is given by $(1 - \delta)k$ times the probability of remaining active forever plus k times the probability of exiting in period 2.

It is worth noting that, along similar lines, a number of authors have argued that uncertainty may have a negative effect on investment rates when investment is irreversible and can be postponed (cf Pindyck [1991] and references therein). In terms of our model, first-period investment is uncertain for type-M firms because there is the possibility of future exit and because investment is irreversible. As a result, first-period investment is lower and expected future investment is greater than it would be otherwise.

[11] Lambson [1991] examines a model in which firms can choose between different technologies. However, the source of uncertainty in his model is demand uncertainty, not firm-specific uncertainty about productivity.

intensive technology has a cost function equal to $\gamma s_t C(q_t/(\gamma s_t))$, with $\gamma > 1$, so that marginal cost, $C'(q_t/(\gamma s_t))$, is lower than under the "normal," or labor-intensive, technology. Suppose in addition that choosing the capital-intensive technology implies the payment of a one-time *sunk* cost S.

It can be shown that, for a given range of values of S, a result similar to Proposition 1 holds: smaller firms grow faster than large firms. The intuition is the same as before: small firms, having a higher probability of exit, prefer to delay investment to the second period, which implies that they expect a higher growth rate between the first and the second period.[12]

IV. ADDITIONAL EMPIRICAL IMPLICATIONS

The model in the preceding section has been developed primarily as a means of explaining the empirical evidence of a negative relation between growth and size. However, sunk costs have additional implications in terms of new firm growth and size. We now consider some of these.

IV(i). *Size, profit rates and average Q*

In the long run, or in the absence of sunk costs, firm profits are given by $s - F$, while output is $s_t h(p)$ (as in the Appendix, we make the normalization $ph(p - \bar{k}) - C(h(p - \bar{k})) - \bar{k}h(p - k) = 1$). Profit rates are thus given by $(s_t - F)/(s_t h(p - \bar{k}))$. In particular, if the value of F is small, then profit rates are approximately equal to $1/h(p - \bar{k})$—that is, constant with size. Since the model is stationary (because there are no sunk costs), the same is true for Tobin's average Q values; that is, average Q is constant with size (average Q is the ratio between discounted profits and the value of the capital stock).

Now consider what happens in the first period when there are sunk costs. Large firms set capacity close to the long-run level. Small firms, however, only invest up to a fraction of their optimal long-run capacity. Since output price is constant and the cost function is convex, the loss in profits from a

[12] It is interesting to note that the technology choice model may also generate an inverted U-shaped relation between size and expected growth. To do so, we would have to consider a fourth efficiency type, Medium-Low, and find parameter values such that: (i) a type-H firm chooses the capital-intensive technology in all periods; (ii) a type-M firm chooses the labor-intensive technology in period one and switches to the capital-intensive technology in the second period conditional on efficiency not decreasing; (iii) a type-ML firm chooses the labor-intensive technology in period one and switches to the capital-intensive technology in the second period conditional on efficiency increasing.

Doms, Dunne, and Roberts [1994] present evidence that is both consistent with our model and the prediction of a U-shaped relation between size and growth. They find that "increases in the capital intensity of the input mix and increases in the use of advanced manufacturing technologies are negatively correlated with plant exits and positively correlated with plant growth" (p. 4). They also show that, in some industries, growth rates are highest for medium size firms, somewhat lower for small firms, and lowest for large firms.

suboptimal capacity is less than proportional to the decrease in capacity. This implies that the profit rate will be higher than it would be if capacity were set at the optimum level.

Implication 1. If fixed costs are small, then profit rates in the first period are negatively related to size.

It is worth noting what is meant by "the first period" in the above implication (and, in general, in the paper). Recall we made the assumption that each firm's efficiency becomes perfectly known in period 2. Therefore, "period 1" should be understood as the period in which knowledge about efficiency is still incomplete, or, equivalently, the period in which exit rates of a given generation of firms are still positive. Given our empirical knowledge of exit rates as a function of age, one should consider period 1 to be the first 5 or 10 years.

With one additional assumption, the previous implication can be extended from profit rates to Tobin's average Q values. Suppose that L is close to zero. Then, by Assumption 2, the expected future value of Tobin's average Q is the same for $s_1 = H$ or $s_1 = M$. In the first period, Tobin's average Q will be greater for small firms on account of future profits (because the denominator, kK_1, is smaller for small firms). Finally, by Implication 1, first period profits also imply a higher Tobin's average Q for smaller firms.

Implication 2. If fixed costs and L are small, then average Q in the first period is negatively related to size.

Note that this implication is consistent with the evidence presented in Fazzari, Hubbard and Petersen [1988]. In their sample, smaller firms have higher investment to capital ratios (therefore, higher expected growth rates) and higher Q values as well. However, the explanation provided by the authors is based on financing constraints and not on sunk costs.

IV(ii). *Exit rates and growth rates*

Consider the model in the previous section as it applies to different industries. Assume that the only difference between industries lies in the value of the probability of exit for entrants of type M, $1 - \alpha - \beta$. (What is meant by this assumption, from an empirical perspective, is that all other cross-industry differences have been accounted for.) It is straightforward to show that the greater is the probability of exit, the lower is the optimal first-period capacity for type-M firms (cf Equation 12); and the greater is the expected growth rate for these firms. We thus get the following implication:

Implication 3. Everything else constant, exit rates and expected growth rates for new firms are positively correlated across industries.

Audretsch and Mahmood [1992] present data on growth and survival rates for 18 different US industries. The data look like a cloud of points very close together and one "outlying" observation — the instruments sector — with an unusually high growth rate and an unusually low survival rate. This is consistent with our Implication 3, but, of course, one observation in 18 is hardly statistically significant.

The work of Olley and Pakes [1992] on the US telecommunications equipment industry also presents evidence relating to Implication 3, as well as Implication 1. Technological change and deregulation have caused a major restructuring of this industry in the past two decades. This restructuring has involved increased entry *and exit* rates; in addition, it has implied an increase in industry productivity growth. This observation is consistent with our model. In fact, Implications 1 and 3 jointly state that the higher is the value of $1 - \alpha - \beta$ (the exit rate for M-type firms), the higher is average productivity.

IV(iii). *Degree of sunkness of investment costs*

So far, we have assumed that capacity costs are entirely sunk. A more realistic assumption, however, is that only a fraction of those costs are sunk. As in the preceding subsection, let us assume that different industries differ only according to the degree of sunkness of capacity costs. Consider the small firms' optimal capacity decision in the first period. If the degree of sunkness is zero, then the optimal capacity is simply the long-run optimal capacity, and the expected growth rate is zero. If in turn the degree of sunkness is one, then we obtain the result derived in Section III: a positive expected growth rate. In general, Equation 12 can be extended to account for an intermediate degree of sunkness. It can then be shown that expected growth rates are increasing in the degree of sunkness.[13]

Implication 4 Everything else constant, new firms' expected growth rates and the degree of sunkness of investment costs are positively correlated across industries.

There are several variables that may approximate the degree of sunkness of investment costs, including the percentage of capital goods bought in second-hand markets, capital depreciation rates, advertising and R&D intensity, and the capital/labor ratio. On the other hand, given our interpretation of what the first period means, a good way of computing growth rates corrected for inter-industry differences is to measure the ratio between entry size and average industry size. The greater the expected growth rates of new

[13] In fact, Equation 12 may yield stronger implications if one makes some assumptions about the shape of the cost function. Specifically, if $C''' > 0$ and $C'''' \leqslant 0$, then expected growth is a convex increasing function of the degree of sunkness. A proof of this claim is available from the author. An example satisfying these assumptions is a quadratic increasing marginal cost function.

entrants, the lower their entry size with respect to the average industry size.

Mata [1993] shows that turbulence, defined by the product of the entry, and the exit rates, is a positive determinant of firm start-up size. If we believe that sectors with higher turbulence rates are also sectors with lower sunk costs, then Mata's observation is consistent with Implication 4.

IV(iv). *Financing constraints*

Financing constraints provide an alternative theory of why small firms grow faster than large ones. Firms may start small either because their efficiency is low or because they are cash constrained. Since cash constraints are expected to be less binding after start-up, cash-constrained start-ups should expect higher-than-average growth rates (cf Hopenhayn and Marimon [1993]). As a result, expected growth rates should be higher among small-scale start-ups. Fazzari, Hubbard and Petersen [1988] and Evans and Jovanovic [1989] show that financing constraints indeed influence investment decisions. Evans and Jovanovic also suggest that this effect should induce a negative relation between an entrepreneur's income (or the firm's initial size) and growth. However, the econometric evidence of this relation is not significant in their sample.

In terms of the empirical implications of our model, financing constraints are important for two reasons. First, we should be especially concerned with tests that distinguish financing constraints and our model as alternative theories. Implications 1 and 2, for example, are consistent with both theories. Implications 3 and 4, in turn, are specific to the sunk-cost theory.

The second reason why it is important to consider financing constraints is that, in reality, the effects of both cash constraints and sunk costs are likely to be significant. It is therefore important to derive empirical implications of the two effects jointly. Consider the following simple extension of the model presented before. Suppose that firms enter in period 0 (not in period 1) and that initially *all* firms are financially constrained to a small capacity k_0. In all other respects, the previous model still applies. In particular, suppose firms only differ with respect to the degree of sunkness of capacity costs of their industry. Then we would expect growth rates from period 0 to period 1 to be *decreasing*, not increasing, in the degree of sunkness. We thus get the following test.

Implication 5. Everything else constant, new firms' expected growth rates and the degree of sunkness of investment costs are negatively correlated across industries when firms are cash constrained and positively correlated when they cease to be cash constrained.

Econometrically, the way to implement this test would be to estimate the relation between growth rates and the degree of sunkness of investment costs (controlling for other factors) during each of the first n years upon entry. We should expect this relation to be initially negative, with the absolute value of the coefficient decreasing and eventually becoming positive.

V. FINAL REMARKS

This paper provides a theoretical explanation for the empirically observed negative relation between firm size and firm growth. The idea is that capacity and technology choices involve some degree of sunkness (that is, investments for which value is forgone upon exit). Since small entrants are more likely to exit than are large entrants, it is optimal for small entrants to invest more gradually, and thus experience higher expected growth rates, than is true for large entrants.

While the main objective of the paper is to suggest a theory that explains the data, we also derived empirical implications that go beyond the negative relation between size and growth. With these tests, one can evaluate the robustness of this theory and its predictive power vis-a-vis alternative theories.

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APPENDIX

Proof of Lemma 1: By Assumption 2,

(6)
$$E(q_2 \mid q_1) = E(s_2 h(p) \mid s_1) = s_1 h(p) = q_1.$$

Hence, expected growth, *including all firms*, is zero, regardless of initial size.

In the second period, firms with $s_2 = L$ exit. Expected growth for *surviving firms* starting with $s_1 = M$ is then given by

(7)
$$E\left(\frac{q_2 - q_1}{q_1} \middle| s_1 = M\right) = \frac{\alpha \dfrac{H - L}{L} + \beta 0}{\alpha + \beta} > 0.$$

Expected growth for surviving firms starting with $s_1 = H$ is in turn zero, since all firms survive in the second period. *Q.E.D.*

Proof of Proposition 1: Consider first the firm's decision problem in the second period, given that it will be active (forever). Assuming that installed capacity is zero and denoting by δ the discount factor, profits per period are given by

$$\Pi = pq_t - s_t C(q_t/s_t) - (1-\delta)kq_t - F, \tag{8}$$

since it is not optimal to hold excess capacity. The solution to this problem is given by

$$q_t^* = s_t h(p - \bar{k}), \tag{9}$$

where $\bar{k} \equiv (1-\delta)k$. Optimum profit is

$$\pi(s_t) = s_t\big(ph(p-\bar{k}) - C(h(p-\bar{k})) - \bar{k}h(p-\bar{k})\big) = s_t, \tag{10}$$

where we make the re-normalization $ph(p-\bar{k}) - C(h(p-\bar{k})) - \bar{k}h(p-\bar{k}) = 1$.

For the high-productivity firm, the first-period decision problem is analogous to that of the second-period, since productivity remains constant with probability one. Hence, $K_1 = q_1 = K_2 = q_2 = Hh(p-\bar{k})$. As for the medium-productivity firm, we know that first-period capacity cannot be greater than $Mh(p-\bar{k})$; that is, $K_1 = q_1 \leqslant Mh(p-\bar{k})$. This implies that, in the second-period, capacity (and quantity) are determined according to (9) if the firm's productivity is high or medium. (Notice that while we assumed installed capacity to be zero, the important condition is that installed capacity be lower than the value given by (9).) Finally, if productivity is low, then conditional second-period output is determined by

$$\max\{Lh(p-\bar{k}), \min\{q_1, Lh(p)\}\} \geqslant Lh(p-\bar{k}). \tag{11}$$

We thus have $E(q_2 \mid s_1 = M) \geqslant Mh(p-\bar{k})$.

The first-period decision problem for the medium-productivity firm is given by

$$\begin{aligned}
\max_{q_1} \Pi &= pq_1 - MC(q_1/M) - kq_1 + \frac{\delta}{1-\delta}(\alpha H + \beta M) \\
&\quad - \delta k\big(\alpha(Hh(p-\bar{k}) - q_1) + \beta(Mh(p-\bar{k}) - q_1)\big) \\
&= pq_1 - MC(q_1/M) - kq_1 + \delta(\alpha H + \beta M)\left(\frac{1}{1-\delta} - kh(p-\bar{k})\right) \\
&\quad + \delta kq_1(\alpha+\beta) \\
&= pq_1 - MC(q_1/M) - k(1-\delta(\alpha+\beta))q_1 + \Omega,
\end{aligned} \tag{12}$$

where Ω is independent of q_1. Since

$$k(1-\delta(\alpha+\beta)) > k(1-\delta) = \bar{k}, \tag{13}$$

it follows, by comparison with (8)–(9), that $q_1 < Mh(p-\bar{k})$. Therefore,

$$E(q_2/q_1 \mid s_1 = M) > E(q_2 \mid s_1 = M)/(Mh(p-\bar{k})) \geqslant 1, \tag{14}$$

and the result follows. *Q.E.D.*

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