The *Pre*-Producers

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Abstract

While a start-up firm waits for its sales to materialize, it is a "pre-producer". This waiting period represents a special kind of entry cost. This paper studies how such entry costs influence the several stages of an industry's life cycle. Assuming that the production hazard is rising in the initial stages of pre-production, industry equilibrium entails an eventual "shakeout" of pre-producers as they are squeezed out by the producers who drive industry price down. This seems to fit the experience of the early automobile industry and of the recent dot.com wave.

1 Introduction

To a management scientist, pre-production is a stage in the manufacture of a new product. During this stage, a firm does research and development, builds a manufacturing plant, assembles its workforce, procures the machinery and the inputs, tests its raw materials, tests its output, finds sales outlets, and so on (Levy 1965, p. B-139, Goyal 1973, p. 392). The description refers to concrete steps taken towards attaining a definite goal, and the delay in attaining it is fairly predictable. To a labor economist or sociologist, the term may refer to a period of highly uncertain length during which a person tries to start a small business that may never get formed, or if it ever does get formed and stays afloat, may not generate sales for a long time (Reynolds 1997, Table 2). The term "Pre-producer" has thus been used to describe an entity that is trying to start selling an output that it has never sold before, but the entity can be an unemployed individual, or a start-up firm, or even a giant corporation that is selling other products in other markets.

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For our purposes, a pre-producer is an entity that is trying to but that has not yet succeeded in generating sales of some product. Pre-producers are often found in young industries. The automobile industry, the pharmaceutical industry, and the numerous activities in which the recent wave of dot.com companies tried to engage in all contained many pre-producers. Many of these pre-producers folded without generating any sales. Carroll and Hannan (2000) report that at the tail end of the 19th century some 90% of all automobile pre-producers never sold a single car – the median pre-production time was less than a year but some were at it for more than 10 years. The top panel of the first figure shows the number of pre-producers and their entry, and the corresponding series for producers. Note that pre-producers were around when the automobile industry was young. The middle panel shows a declining price and rising output over the entire period. The bottom panel shows the estimated smoothed hazard rate and survivor function for an automobile pre-producer.

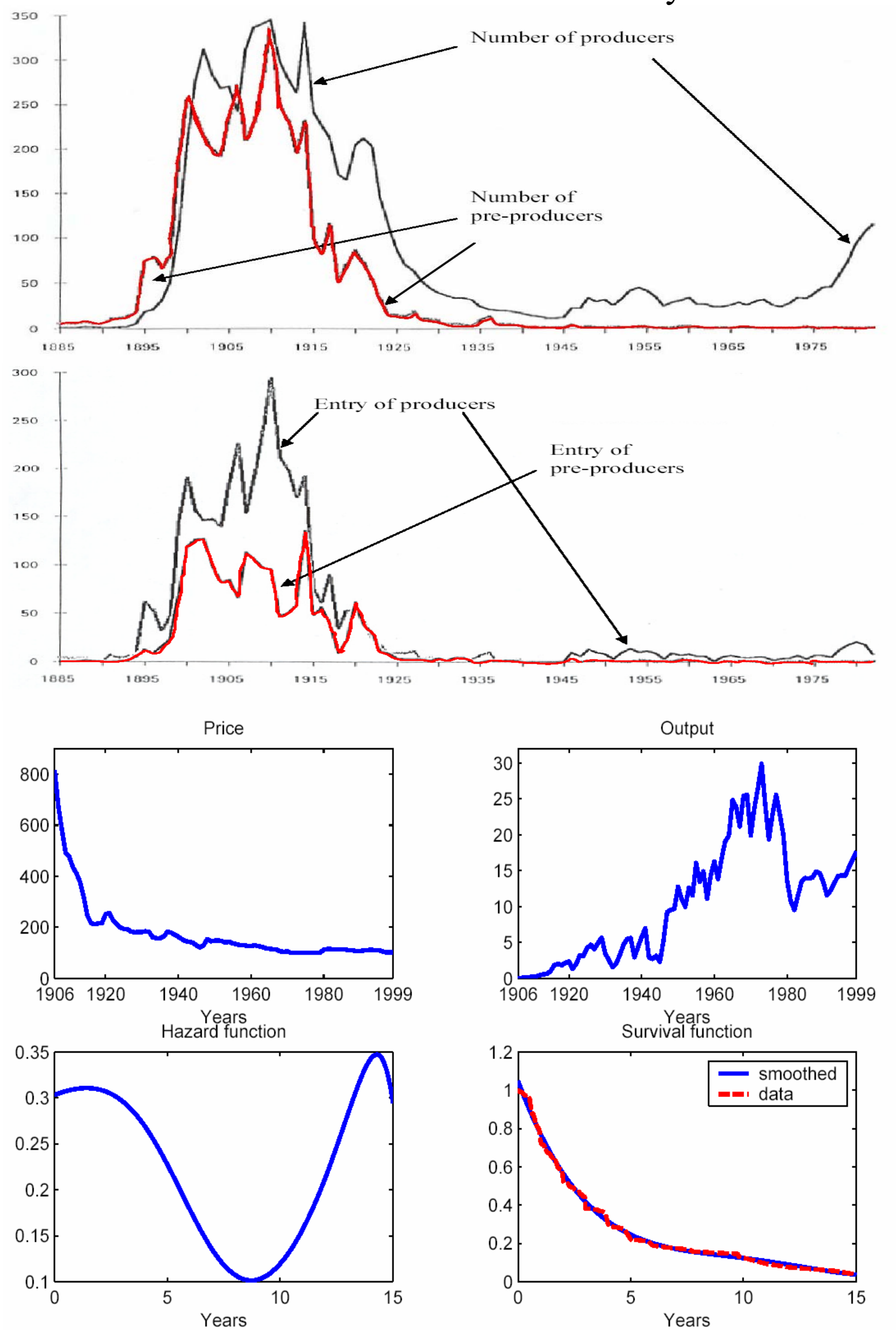
Pre-production is an investment in the form of a waiting time. The cost of such an investment is mainly in the form of earnings that the firm's founders and its employees could earn if they spent their time doing other things. For the purposes of the model, then, the defining moment when the firm is born is when its founders start diverting time from other activities and perhaps also incur a direct entry cost. Pre-production ends when sales start coming in. In practice, there seem to be two reasons for why we see pre-production periods:

1. *Investment lags.*—The the average research project takes between 1 and 2 years to complete (Pakes and Schankerman 1984). Mansfield *et al.*(1981) report shorter delays for how long it takes firms to copy the inventions of others. Elsewhere the lag is much longer: The average time from a drug's first world-wide patent application to its approval by the FDA is 13 years (Dranove and Meltzer 1994). And time-to-build delays for plants are about 2 years (Meyer 1960).

2. *Learning lags.*—Even when sales start, they may be negligible. The firm may need to learn about the various production and selling stages. The more complex the activity, the more S-shaped the learning curve is likely to be (Jovanovic and Nyarko 1995), and the periods before the sudden rise in productivity will look like a pre-production episode.

Viewed generally, the model falls in a class in which a firm's TFP grows stochastically as the firm ages. I make specific and restrictive assumptions on the TFP-growth process in order to be able to derive the industry dynamics. Throughout, I shall ask whether heterogeneity matters for industry aggregates – this part is still highly preliminary, though I make some conjectures. I then show evidence from several sources about the existence of stage in the firm's life that one may usefully call pre-production.

The U.S. Automobile Industry



2 Two benchmarks

This section draws out a parallel between the following two environments: The first is for a group of identical firms that become more productive as time goes by. The second is for a group of firms some of which succeed in becoming producers and some that don't. Total output and industry price are always the same in the two cases. In the first case, however, firms move ahead together, whereas in the second case some produce before others. Understanding these two benchmarks will help us understand the material that comes later.

In all that follows we shall be talking about an industry with a demand curve $q = D(p)$, where q is industry output and p industry price. We shall always be talking about a continuum of firms that do not feel like they can affect p. In every case, potential entrants into the industry suddenly become aware of its existence at date zero. For our purposes, this awareness defines the industry's birth.

2.0.1 Homogeneous LBD

Every firm must wait z periods until it generates sales. The rate of interest is r. The output of each firm is

$$y_t = \begin{cases} 0 & \text{if } t < z, \\ \theta & \text{if } t \geq z. \end{cases} \tag{1}$$

Assume that θ and z are known. There is, in effect, a learning delay of z periods. I call this learning by "doing" because the firm must be present in the industry and not collecting income w elsewhere. Assuming that time is continuous and that no other costs of entry exist, the free-entry condition then says that

$$\frac{w}{r} = \theta e^{-rz} \frac{p}{r}, \tag{2}$$

so that the equilibrium price is

$$p = \frac{1}{\theta} e^{rz} w \tag{3}$$

Entrants require a mark-up over foregone-earnings cost of $(e^{rz} - 1)$.

The introduction of a common waiting time does 3 things

1. It delays production by z periods, (all entry takes place at $t = 0$).

2. It raises the equilibrium price from w to $e^{rz}w$, and

3. It produces no dynamics in p and q, and gives rise to no exits.

This model has implications that are almost identical to one in which the costs were direct, in terms of goods. I.e., if all firms had to pay a common dollar cost of entry ϕ, where $\phi = \frac{w}{r}(e^{rz} - 1)$. Foregone earnings are an economic cost that arises when the production hazard is low (e.g., zero as it is here) in the early periods of a firm's life.

Since firm size is fixed at 1, profits depend only on the markup. The demand curve therefore determines only the number of entrants, n_0, which, since aggregate output after date z is θn_0, is given by

$$n_0 = \frac{1}{\theta} D\left(\frac{1}{\theta} e^{rz} w\right).$$

2.0.2 Heterogeneous LBD

We now change things so that only a fraction θ of the entrants can ever produce anything, but those that do produce one unit. Who is who becomes known only at date z. Therefore a firm's output of each firm is

$$y_t = \begin{cases} 0 & \text{if } t < z, \\ \left[\begin{array}{ll} 1 & \text{with prob } \theta \\ 0 & \text{with prob } 1-\theta \end{array}\right. & \text{if } t \geq z. \end{cases} \tag{4}$$

Because firms are risk neutral, the free-entry condition is still (2) and price is still given by (3) The equilibrium markup now reflects the delay z and the probability θ. Aggregate industry output is, at all dates, the same as in example 1:

This example contains the essential features of the equilibrium in the subclass of more general cases that we may call empirically relevant. The properties of this equilibrium that will, in spirit, survive in the more general setups are

1. All entry takes place at $t = 0$
2. As the industry matures price falls – from $+\infty$ to p in (3) and the fall occurs at date z
3. At date z, there is a mass exodus of the fraction $1-\theta$ of firms that discover that they will not manage to produce anything. We may call this a "shakeout." The market values of the failed pre-producers then fall. The portfolio of all firms would remain stable in value, but the idiosyncratic component of stock returns would show great variance for the first and only time at date z.
4. The total number of entrants n_0 now must be such that the output of the *survivors* is $D\left(\frac{e^{rz}}{\theta} w\right)$.[1]

[1]Since total output of survivors will be θn_0,

$$n_0 = \frac{1}{\theta} D\left(\frac{e^{rz}}{\theta} w\right).$$

Does ex-post heterogeneity matter?— Aggregate variables – p_t and q_t – are identical in the two examples. But individual firm fortunes are turbulent in the second example where there also is much more ex-post heterogeneity.[2] It is natural to ask whether this conclusion generalizes – if not exactly, then at least in spirit. That is, we shall ask "Does ex-post heterogeneity in production success matter for aggregates, or only for individual fortunes?" The answer will be a resounding "no." The differences will be the most apparent when demand is elastic and when, as a result, incentives to exit will differ the most in the two cases. The following two sections again contrast the homogeneous and heterogeneous cases, but in a more general setting.

3 General homogeneous learning

Suppose that every firm learns as its age (measured as the time spent in the industry) grows. Output, y_t, obeys a learning curve with

$$y_0 = 0, \quad \dot{y}_t > 0, \quad \text{and} \quad \lim_{t\to\infty} y_t = 1. \tag{5}$$

Potential entrants into the industry suddenly become aware of its existence at date zero. If equilibrium price p_t declines over time, the optimal time to enter is immediately. Then let t denote the age of the industry and the age of every surviving firm in that industry. A declining p_t also means that it will never pay to exit and re-enter. Therefore we can regard every exit as final. Let n_0 be the number of entrants, and let n_t be the number of firms in the industry. Industry output is

$$q_t = n_t y_t$$

Let v_t be the value of the representative firm. The firm's revenue is $p_t y_t$. Because firms are the same, they will never strictly prefer to exit the industry, for if they ever did, industry supply would drop to zero, and that would not be an equilibrium. Therefore, each firm is happy to stay in the industry, or at most indifferent between staying in and exiting. The present value of the firm is

$$v_t = \int_t^\infty e^{-r(s-t)} p_s y_s ds, \tag{6}$$

whence we have, after differentiating w.r.t. t,

$$\dot{v}_t = r v_t - p_t y_t$$

If, e.g., $D(p) = p^{-\alpha}$ then

$$n_0 = \theta^{\alpha-1} \left(e^{rz} w\right)^{-\alpha}$$

Thus a higher θ raises n_0 if the elasticity of demand, $-\alpha$ is less than one in absolute value. Otherwise it lowers n_0.

[2] The idiosyncratic component of stock returns has in recent years become more important, and the aggregate component less important (Campbell et al 2002).

The nature of equilibrium depends on whether D is elastic or inelastic. We discuss each case in turn.

Inelastic demand.—This case gives rise to eventual exit of firms. If demand is inelastic, $mD(wm)$ is increasing in m. Then n_t is decreasing in y. Therefore there is a number τ when for the first time $p_t y_t = w$. Thereafter there is continual exit. But q_t is still increasing. We determine n_0, τ from the free-entry condition, and from the condition that τ is the date at which income of producers first falls to w given that no one has yet exited (so that $n_t = n_0$),

$$n_0 = \frac{1}{y_\tau} D\left(\frac{w}{y_\tau}\right) \tag{7}$$

Define the exit region

$$E = \left\{ t \geq 0 \mid v_t = \frac{w}{r} \right\}.$$

For the cases we shall look at, E will be an interval, i.e. $E = (\tau, \infty)$. On the exit region $\dot{v}_t = 0$, so that

$$v_t = \frac{1}{r} p_t y_t,$$

i.e.,

$$p_t y_t = w$$

so that if there is exit, the limiting value (5) gives

$$\lim_{t \to \infty} p_t = w \tag{8}$$

Then $-\dot{n}$ (recall that $\dot{n} \leq 0$) is the number of firms exiting. Then on the exit region,

$$q_t = n_t y_t = D\left(\frac{w}{y_t}\right)$$

Therefore

$$n_t = \frac{1}{y_t} D\left(\frac{w}{y_t}\right).$$

Elastic demand.—In this case $D^{-1}(n_0 y_t)\, y_t$ *rises* with t, and a firm's sales rise over time even though price is falling. In this case, the solution to (7) does not signify that an exit date has been reached. There is never any exit.

Free entry.—The free-entry condition is

$$v_0 = k + \frac{w}{r}, \tag{9}$$

which means that n_0 solves[3]

$$k = \int_0^\tau e^{-rt} \left[D^{-1}(n_0 y_t)\, y_t - w \right] dt. \tag{10}$$

[3] Because $k = \int_0^\infty e^{-rt} p_t dt - \frac{w}{r} = \int_0^\infty e^{-rt}(p_t - w)\, dt$, and $\int_\tau^\infty e^{-rt}(p_t - w)\, dt = 0$.

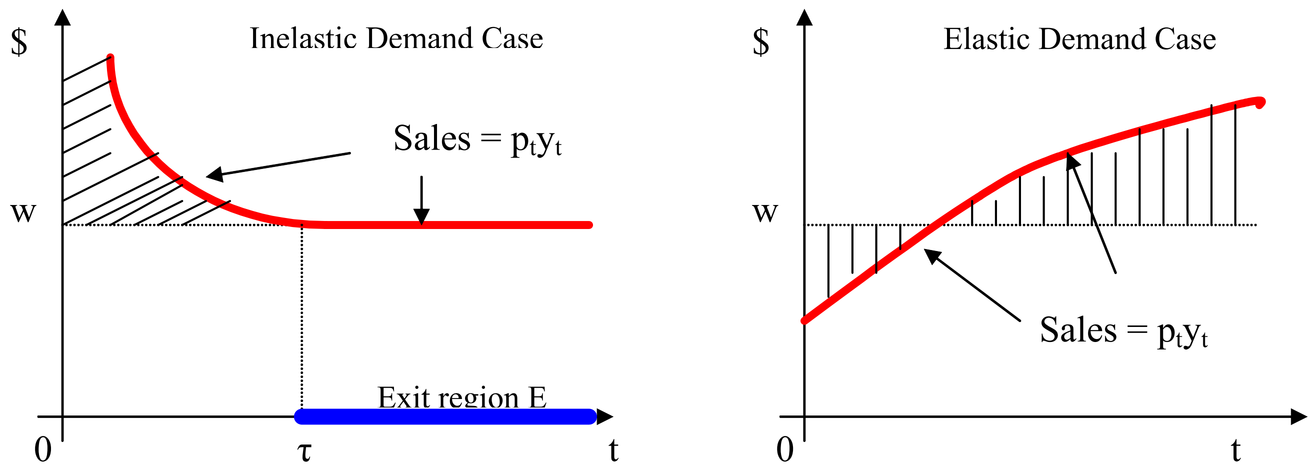


Figure 1: REPRESENTATIVE FIRM EQUILIBRIUM FOR TWO TYPES OF DEMAND

Equilibrium.—Equilibrium is a set of functions v, p, and output $q = D(p)$ such that (6), (7) and (9) hold.

In Figure (1) the first panel is the inelastic-demand case in which exit starts at date τ. The second panel is the elastic-demand case in which no exit takes place. Regarding condition (10), in the elastic case the present value of the shaded areas must equal k. In the second panel, the present value of the second shaded are must equal k plus the present value of the first area.

Later on I shall refer to this deterministic environment as the "L" environment. Note that in an L environment

- If demand is elastic (the right panel in Figure 1), a firm's sales will rise with its age
- If demand is inelastic, (the left panel in Figure 1), a firm's sales will fall with its age.

3.1 Unit-elastic demand

If demand is unit elastic – $q = A/p$, so that

$$n_0 y_t = \frac{A}{p_t}.$$

Each firm's sales are constant

$$p_t y_t = \frac{A}{n_0}. \tag{11}$$

No exit takes place, and the free-entry condition then implies

$$\frac{A}{n_0} = w + rk. \tag{12}$$

That is the flow of sales must compensate for the foregone earnings plus the interest payment on the entry cost. Then (11) and (12) imply that

$$p_t = \frac{w + rk}{y_t} \tag{13}$$

so that

$$\lim_{t\to\infty} p_t = w + rk \tag{14}$$

Steady-state output is

$$n_0 = \frac{A}{(w + rk)}. \tag{15}$$

We shall see that – at least for this special case – with the same demand structure and same collective output, the pre-producer case will look quite different

4 General heterogeneous learning: The pre-producers

We now introduce differences among firms' z's. Conditional on its age, t, and its type, z, the firm's output is

$$Y_{t,z} = \begin{cases} 0 & \text{if} \quad t < z \\ 1 & \text{if} \quad t \geq z \end{cases}$$

as plotted in Figure 2. Ex-ante, firms are the same. Each believes itself to be a random draw from the distribution F_z. The realized z's differ, however, and they are uncorrelated. There is no aggregate uncertainty, so that

$$\int_0^\infty Y_{t,z} dF_z = F_t$$

and F is exogenous. Figure 2 shows the time-path of output firm that becomes productive at age t. Let t be random and i.i.d. over firms, and let F_t = cumulative distribution of t. Mean output is just[4]

[4]Discussing his finite-player setting with no aggregate shocks, Loury (1980, p. 399) correctly notes that an absence of spillovers (imitation, theft of secrets, e.g.,) implies that the z's are mutually independent. In a finite population, the converse is also true: A presence of spillovers would imply a *de*pendence of the z's. But in a continuum, the converse fails in the following sense: Let F_t solve an "intergenerational-spillover" differential equation

$$\dot{F} = \xi(F) \text{ for}$$

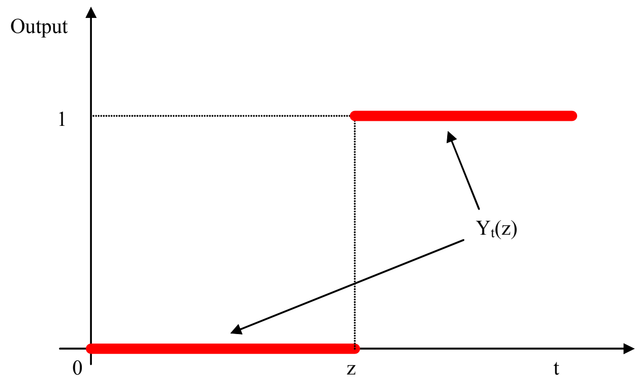


Figure 2: Type-z firm's otput as a function of its age

Each z can be viewed as the waiting time resulting from the use of a slightly different technique or model design. The assumption that z is not known before entry and it may have considerable variance makes the most sense in a new industry in which many approaches look similar before the fact. In a new industry that uses a new technology, many designs and techniques may look equally promising ex-ante. Elsewhere, the best technique(s) have already been identified, they are the only ones that entrants would try and as a result the dispersion of F would be smaller.[5]

The entry cost is k and production costs are zero. Alternative earnings for every firm are w per unit of time, and w is exogenous. Re-entry is never optimal because price does not increase.

The distribution of production times, F.—We now assume that F_t is continuous. Until it has realized its z, the firm updates its future prospects using Bayes Rule.

An example is the exponential distribution $F_t = 1 - e^{-\lambda t}$ analyzed above which satisfies

$$\dot{F} = \lambda (1 - F) . \tag{16}$$

Players' optimal entry and exit behavior is the same regardless of whether or not they are aware of the (negative) spillover mechanism in (16). Of course, this conclusion would change if a firm could do something to influence its probability of becoming a producer – e.g., by contacting a producer.

As an aside, note the that (16) is an equation of the type mentioned by organizational ecologists (e.g., Carroll and Hannan 2000) who emphasize that business formation (i.e., $\dot{F}$) may depend on the "density" of existing producers (i.e., F).

[5]More generally, let x be a technique, and $G(z, x)$ a distribution of waiting times z resulting if technique x is used. Let $H(x)$ be the distribution of techniques among the entrants – determined by the content of their prior experience. Then we may say that

$$F(z) = \int G(z, x)\, dH(x) .$$

Define the hazard rate of F as

$$h_t = \frac{f_t}{1 - F_t}.$$

We shall assume that the appearance of the industry at hand is unforeseen. Somehow the industry is "born" at date zero and all the firms realize that the market demand for the product is given by $p = D(q)$. Suppose all firms enter at $t = 0$. Then the age of every firm is $= t$ and the instantaneous conditional probability that a pre-producer becomes a producer is just h_t.

Evolution of output.—Producers are all alike; each sells one unit. Since the demand curve is constant, no producer will ever exit. Thus output equals the number of producers. Let n denote the number of firms, and let q be the number of producers. Then $q - n$ is the number of pre-producers. Thus the differential equation for q is

$$\dot{q} = (n_t - q_t)\, h_t. \tag{17}$$

If firms exit, n_t decreases. Everyone enters as a pre-producer so that $q_0 = 0$.

The values of firms.—Producers never exit, pre-producers sometimes do. Therefore the date-t value of a producer is

$$V_t^* = \int_t^\infty e^{-r(s-t)} p_s ds. \tag{18}$$

As long as $V \geq w/r$, a pre-producer is happy to stay in the industry.

Denote the exit region by $E = \left\{t \geq 0 | V_t = \frac{w}{r}\right\}$. Let T be the date, possibly infinite, when the last pre-producer exits. The advantage of using continuous time is that when there are no aggregate shocks, in equilibrium, no pre-producer will ever strictly prefer the exit option on the interval $[0, T]$, which means that he would be no worse off if we foreclosed the exit option to him. For for all $t \leq T$ then,[6]

$$V_t = \int_t^T e^{-r(s-t)} p_s \left(\frac{F_s - F_t}{1 - F_t}\right) ds + \frac{e^{-r(T-t)}}{r} \left[\left(\frac{F_T - F_t}{1 - F_t}\right) p_T + \left[1 - \left(\frac{F_T - F_t}{1 - F_t}\right)\right] w\right] \tag{19}$$

Note that (18) and (19) have a similar form.

Later on I shall refer to this stochastic environment where some firms are pre-producers as the "P" environment. I shall assume that $y_t = F_t$, and ask how the two environments differ.

[6] To derive the second equality below note that Bayes' rule gives us

$$\Pr\{\text{output} = 1 \text{ at date } s \mid \text{output} = 0 \text{ at date } t\} = \frac{F_s - F_t}{1 - F_t}.$$

4.1 Equilibrium

Equilibrium consists of functions V, V^*, p, q, and n satisfying (18), (19), and the following restrictions:

1. *Demand = Supply.*—q satisfies (17), and

$$p_t = D(q_t). \tag{20}$$

2. *Free entry.*—Every firm enters as a pre-producer. If p falls over time, all firms will enter at the same date $t = 0$, and drive the present value of entry to zero:

$$V_0 = \frac{w}{r}, \tag{21}$$

   Some examples will behave badly unless we assume a fixed cost of entry to the right-hand side of (21) in addition to the foregone-earnings cost.

3. *Optimal exit.*—Producers do not exit and their value, V^*, satisfies (18). Pre-producers do not exit while $V_t > w/r$, and V satisfies (19). If pre-producers exit, this must happen for dates $t \in E$, where

$$V_t = \frac{w}{r}. \tag{22}$$

4.2 Analysis

Suppose that the set E has an interior, and suppose t is a point in that interior. Then $V_t = w/r$ and $\dot{V}_t = 0$. Then (39) implies

$$V_t^* = \left(1 + \frac{r}{h_t}\right)\frac{w}{r}, \tag{23}$$

and substituting from (18) for V^* gives

$$\left(1 + \frac{r}{h_t}\right)\frac{w}{r} = \int_t^\infty e^{-r(s-t)} p_s ds. \tag{24}$$

we can differentiate both sides of (24) w.r.t. t to obtain

$$-\frac{rh_t'}{h_t^2}\frac{w}{r} = -p_t + r\left(1 + \frac{r}{h_t}\right)\frac{w}{r},$$

which implies the following price mark-up at date t:

$$\frac{1}{w}p_t = 1 + \frac{1}{h_t}\left(r + \frac{h_t'}{h_t}\right). \tag{25}$$

Proposition 1 *If t is an interior point of E, then $h_t' \geq 0$.*

Proof. Since producers do not exit, p_t cannot increase. Together with (18) this implies that $V_t^* \leq p_t/r$. But then (23) implies

$$\frac{1}{w}p_t \geq 1 + \frac{r}{h_t}.$$

Together with (25) this implies the result. ■

4.2.1 Equilibria in "L" vs. "P" environments

Let the superscript "P" denote a pre-producer allocation, and the superscript "L" denote the LBD allocation. We wish to put the two environments on an equal footing as we did in Section 2. This means giving them the same demand curve $q = D(p)$, and the same potential to produce aggregate output in the sense that

$$y_t = F_t. \tag{26}$$

This condition says that the same fixed number of firms would, in the two environments, produce the same aggregate output at each date.

Sufficient conditions for exit.—When would we expect a big shakeout? When the first few can supply the whole market and when many things look plausible ex-ante. This is the story of the internet and the automobile

Proposition 2 *Suppose that as $t \to \infty$, $h_t \to h_\infty$. Then exit must take place if*

$$h_\infty (p_\infty - w) \leq r.$$

Proof. From (39),

$$V_t = \frac{h_t V_t^* + \dot{V}_t}{r + h_t}. \tag{27}$$

As $t \to \infty$, $V \to \frac{h_\infty V_\infty^*}{r+h_\infty} = \left(\frac{h_\infty}{r+h_\infty}\right)\frac{p_\infty}{r}$ so that exit must take place if

$$\left(\frac{h_\infty}{r + h_\infty}\right)\frac{p_\infty}{r} \leq \frac{w}{r}$$

i.e., if $p_\infty \leq w\left(1 + \frac{r}{h_\infty}\right)$, which leads to the claim. ■

We now wish to show that under some circumstances the time path p^{P} is a counter-clockwise twist of the time path p_t^{L}. The should be true for the inelastic-demand case and the intuition goes as follows: To keep pre-producers in the game, the price must compensate them for the risk of failure (let us recall that pre-producers are foregoing income the entire time that they are in the industry). In particular this must occur in the limit at t gets large, i.e., $\lim_{t\to\infty} p^{\mathrm{P}} > w$. But in the limit all producers are producing one unit and so $p^{\mathrm{L}} \to w$. But since pre-producers are risk neutral. But they would be strictly better off at date zero unless more of them were to enter. Hence $p_0^{\mathrm{P}} < p_0^{\mathrm{L}}$. TO BE CONTINUED

4.2.2 Example 3: A constant production hazard

Now we drop the superscripts because we shall deal only with "P" environments. Suppose $F_t = 1 - e^{-\lambda t}$ so that $h_t = \lambda$. In this case the pre-producers are not accumulating any intangible capital as they wait. Then for $t < \tau$,

$$q_t = n_0 \left(1 - e^{-\lambda t}\right).$$

By the previous Proposition, E cannot have an interior, and since p cannot increase, E must consist of a single point that we shall call T. But then the RHS of (24) is p/r, from which

$$p_t = \left(1 + \frac{r}{\lambda}\right) w, \tag{28}$$

for all $t \geq T$.[7] All exit happens at T. For if it did not, more producers would appear after t and V would fall below w/r. Then the two unknowns are n_0 and T. The two equations that determine them are the free entry condition (reproduced after evaluating (38) at $t = 0$),

$$k+\frac{w}{r} = \int_0^T e^{-rt} D^{-1}\left(n_0\left[1 - e^{-\lambda t}\right]\right)\left(1 - e^{-\lambda t}\right) dt + e^{-rT}\left[\left(1 - e^{-\lambda T}\right)\left(\frac{1}{r} + \frac{1}{\lambda}\right) w + e^{-\lambda T}\frac{w}{r}\right], \tag{29}$$

because $p_T\left(\frac{1}{r} + \frac{1}{\lambda}\right) w$ is the present value of profits after exit is over, and the condition that the price function be continuous at T, which means that

$$p_T = D^{-1}\left(n_0\left(1 - e^{-\lambda T}\right)\right) = \left(1 + \frac{r}{\lambda}\right) w \tag{30}$$

Condition (29) simplifies to

$$k + \frac{w}{r} = \lambda \int_0^T e^{-rt} D^{-1}\left(n_0\left[1 - e^{-\lambda t}\right]\right)\left(1 - e^{-\lambda t}\right) dt + we^{-rT}\left[\frac{1}{r} + \frac{1}{\lambda}\left(1 - e^{-\lambda T}\right)\right]. \tag{31}$$

The case of unit-elastic demand. When demand is unit-elastic the L environment of Section 3 gives rise to no equilibrium exit, whereas in the P environment we get exit. Assume, then, that

$$D^{-1}(q) = \frac{A}{q}.$$

Then (30) and (31) read

$$p_T = \frac{A}{n_0\left(1 - e^{-\lambda T}\right)} = \left(1 + \frac{r}{\lambda}\right) w, \tag{32}$$

[7] The same conclusion follows from (25) if we note that $h' = 0$.

and output therefore stabilizes at

$$q_T = \left(\frac{\lambda}{r+\lambda} \right) \frac{A}{w}. \tag{33}$$

We can contrast (32) and (33) to (14) and (15). MORE HERE....

Free entry says that

$$k + \frac{w}{r} = \frac{\lambda A}{n_0} \int_0^T e^{-rt} dt + we^{-rT} \left[\frac{1}{r} + \frac{1}{\lambda} \left(1 - e^{-\lambda T}\right) \right],$$

i.e.,

$$k + \frac{w}{r} = \frac{\lambda A}{r n_0} \left(1 - e^{-rT}\right) + we^{-rT} \left[\frac{1}{r} + \frac{1}{\lambda} \left(1 - e^{-\lambda T}\right) \right]$$

Eliminating n_0 via (32) leaves us with one equation in T:

$$k + \frac{w}{r} = \left(1 - e^{-rT}\right) \left(1 - e^{-\lambda T}\right) \left(1 + \frac{\lambda}{r}\right) w + we^{-rT} \left[\frac{1}{r} + \frac{1}{\lambda} \left(1 - e^{-\lambda T}\right) \right] \tag{34}$$

At $T = 0$ the RHS of (34) equals w/r. At $T = \infty$ it equals $\left(1 + \frac{\lambda}{r}\right) w$. Therefore exit takes place if

$$k + \frac{w}{r} < \left(1 + \frac{\lambda}{r}\right) w,$$

i.e., if

$$\frac{k}{w} < 1 + \frac{\lambda - 1}{r}. \tag{35}$$

The LHS of (35) is the ratio of two kinds of entry costs. The numerator is the direct, sunk cost of entry. The denominator is the foregone-earnings component of the entry cost. It makes sense that exit should occur when this ratio is low.

Comparison to the example in section 2.3

- In both examples, the shakeout is sudden: All remaining pre-producers exit simultaneously.

- These values at which the product price eventually stabilizes are similar – compare (28) with (3). In both cases the markup over w depends on the ratio of r to the probability of success. Demand does not affect the final price at all.

- Instead of being common to all, z is drawn independently from a distribution with a positive variance. Firms therefore start to produce in sequence, and the price decline is not sudden, but gradual.

4.2.3 A Bell-shaped hazard

A generalization of the time-to-build spike is presumably a bell-shaped hazard. Figure 4 shows that it can arise in practice. In the region where the hazard is rising, we may expect sometimes to see a non-degenerate interval E of exits because now the passage of time involves a tradeoff between a declining price and a rising hazard of production. An exit rate may be able to balance the two forces off exactly and thereby keep the pre-producers indifferent between staying in the game and quitting.

Conjectured equilibrium when h is bell-shaped.—One type of equilibrium we expect to see will follow from the following observation: If T is the date at which the last pre-producers leave, then $p_t = p_T$ for $t \geq T$. Then (24) implies that

$$\frac{1}{w} p_T = 1 + \frac{r}{h_T} \tag{36}$$

Together, (25) and (36) give us a hint as to what should happen when h is single-peaked. Suppose h_t is bell-shaped – roughly as in Figure 4. This shape is reproduced in the bottom panel of Figure (3). Let T be the age at which h peaks. Suppose $E = [\tau, T]$. Then the following behavior

1. n_0 firms enter at date 0.

2. For $t \in [0, \tau]$,
$$q_t = n_0 F_t \quad \text{and} \quad p_t = D(n_0 F_t) \tag{37}$$

3. For $t \in [\tau, T]$, (25) holds, and p_t declines gradually to p_T in (36). Price declines steadily from $D^{-1}(0)$ at $t = 0$ to $D(n_0 F_\tau)$ at $t = \tau$. At τ, p_t has a kink, becoming more shallow, as exit begins.

4. Since the price cannot jump at τ, the RHS of (37) must equal the RHS of (25):
$$D(n_0 F_\tau) = \left[1 + \frac{1}{h_\tau}\left(r + \frac{h'_\tau}{h_\tau}\right)\right] w.$$

No pre-producer stays around beyond T. If some did stay, p would continue to fall, and so would h, thereby reducing V below w/r, as the dashed line of the middle panel shows. No pre-producer would want to keep trying if the chances of succeeding are getting slimmer at the same time that the rewards from success – i.e., p_t – are declining. In this sort of equilibrium no pre-producers should remain after the hazard rate becomes permanently negatively sloped. Figure 4 gives some estimates of h which do indeed contain a negatively-sloped portion of h, so we look to see if other equilibria exist that will have that feature.[8]

[8] Seemingly appealing at first is the Pareto distribution

$$F_z = 1 - \left(\frac{z}{z_{\min}}\right)^{-\theta} \quad \text{for} \quad z > z_{\min},$$

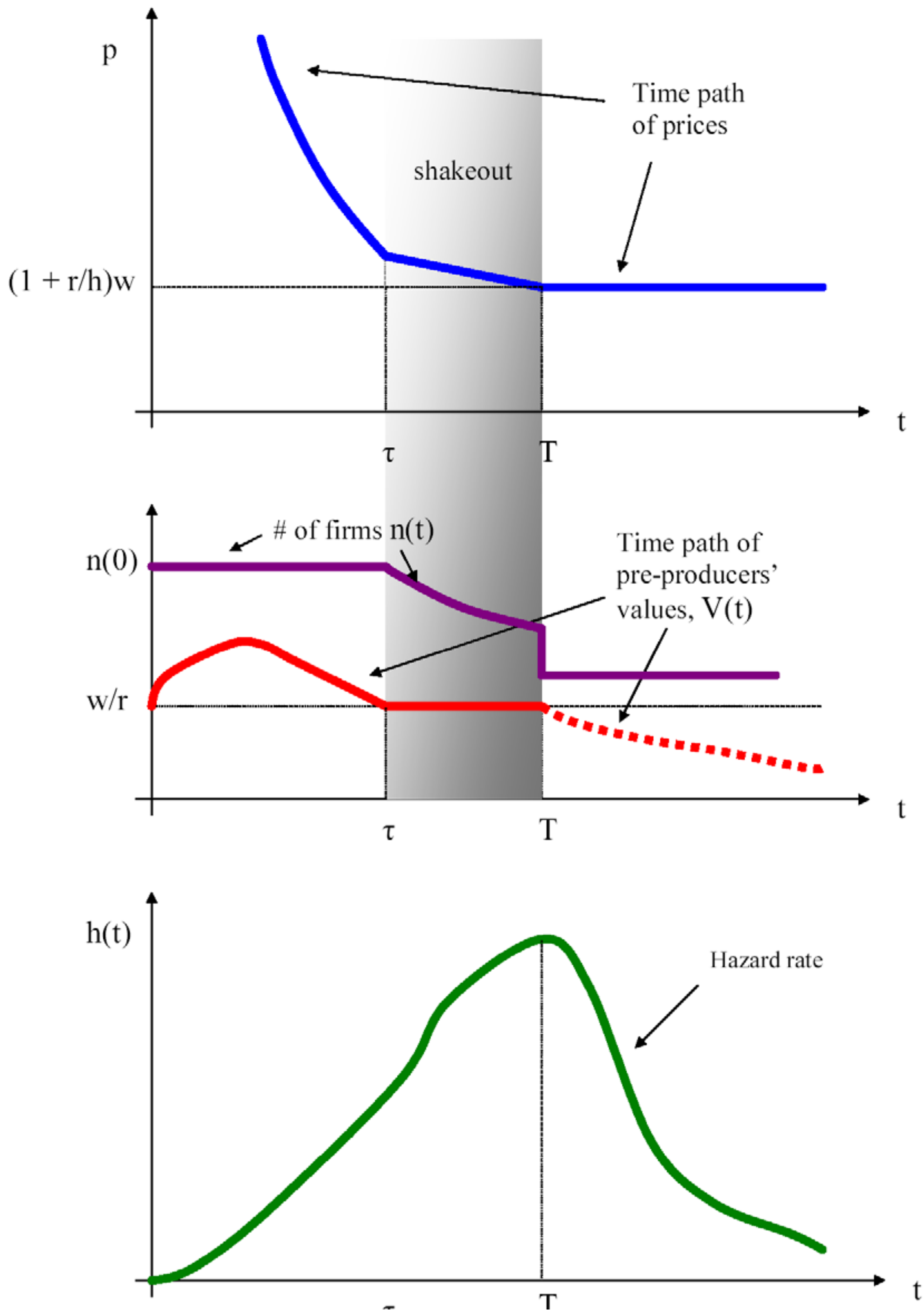


Figure 2: Conjectured equilibrium when the hazard is bell-shaped

Figure 3 portrays this equilibrium in the case where $k = 0$ so that in the middle panel $V_0 = w/r$ by the free-entry condition. Appendix 1 provides, in rough, a set of sufficient conditions for an equilibrium of this sort to exist. But what about the intuition? Why should exit end exactly when $h' = 0$? If exit ends earlier, then some pre-producers must be left. Suppose, on the contrary, that $h'_T > 0$, and that no pre-producers remain. Then price remains constant at p_T. But the chance of starting to produce at the next instant will be higher. So the value of the option to wait will increase. But this implies that there will be an arbitrage opportunity since the option value of waiting was previously equal to zero. So there is a contradiction. As we have already shown that exit cannot happen continuously when $h' < 0$, the only candidate is the peak.

5 Obsolescence of capital

In early 2000 many internet companies traded for many times their earnings, with price-earnings ratios often defying definition because the companies in question had no earnings! Then many lost value. Something of the sort happens in the present model because every pre-producer has precisely zero earnings, and yet has a positive present value of these earnings. The model has no aggregate shocks and cannot generate an aggregate crash[9] but it naturally gives rise to volatility in individual company stock prices, both up and down. Related to this is the valuation of "intangibles." We may also call it "organization capital," as Atkeson and Kehoe (2002) do. [10]

A firm has two kinds of capital: The sunk cost k which may be on its books, and the productivity growth produced by waiting which is an intangible. For a producer this intangible has given rise to actual productivity growth from a level of zero to a level of unity. For a *pre*-producer, however, this intangible capital materializes in

because it has the property of a minimum time to produce, $z_{\min}$ followed by a non-degenerate distribution of z, and a hazard rate of

$$h_z = \begin{cases} 0 & \text{for} \quad z < z_{\min}, \\ \frac{\theta}{z} & \text{for} \quad z \geq z_{\min}. \end{cases}$$

This hazard function has a sudden upward jump at $z_{\min}$, but because it lacks a continuously rising portion. As a result E is once again a singleton, as it was in the exponential case above.

[9] See Barbarino and Jovanovic (2003) for a model of aggregate crashes based on demand uncertainty.

[10] Atkeson and Kehoe have a one-commodity vintage-firm model. Chari and Hopenhayn (1991) have a one-commodity vintage technology model. A firm there is made obsolete not by the decline of the product price (as is the case in my model) but rather by a rise in the wage. More productive, better cohorts bid up the prices of inputs and thereby make the older cohorts obsolete. The two mechanisms are different. Mine is more relevant for analyzing the obsolescence of capital that is tied to making a particular product. The vintage-firm approach is better for analyzing obsolescence of capital in the aggregate. A test between the vintage model and this model: An a particular industry cohorts of *producers* are equally productive here whereas in theirs, each has a higher learning curve.

the form of an expected instantaneous productivity increase of h_t. As p declines, the output – actual or potential – of the firms in the industry gradually gets cheaper relative to other goods and therefore the capital – tangible and intangible alike – becomes obsolete. This obsolescence takes place in both firms, but the obsolescence of producers' capital is easier to define, so let us start with that.

Producers' capital.—For a producer, physical and intangible capital are at a maximal possible level. The total value of that package is V_t^*. Producers are becoming strictly worse off over time as long as $\dot{p} < 0$: From (18),

$$\dot{V}_t^* = rV_t^* - p_t < 0$$

because since p cannot rise, $\dot{p}_t < 0$ implies $V_t^* < p_t/r$. Of course, the very fact that p – a relative price – declines over time implies that the commodity is gradually becoming obsolete in this sense.

Pre-producers' capital.—A pre-producer's physical capital is at its maximal level, but his intangible capital is not. In terms of value the penalty is $V_t^* - V_t$. Since

$$F_t = 1 - \exp\left\{-\int_0^t h_u du\right\} \quad \text{and} \quad \frac{F_s - F_t}{1 - F_t} = 1 - \exp\left\{-\int_t^s h_u du\right\},$$

(19) can also be written as

$$\begin{aligned} V_t &= \int_t^T e^{-r(s-t)} p_s \left(1 - \exp\left\{-\int_t^s h_u du\right\}\right) ds + \\ &\quad + \frac{e^{-r(T-t)}}{r} \left[\left(1 - \exp\left\{-\int_t^T h_u du\right\}\right) p_T + \exp\left\{-\int_t^T h_u du\right\} w\right] \\ &= V_t^* - \int_t^T p_s \exp\left\{-\int_t^s (r + h_u)\, du\right\} ds - \frac{e^{-r(T-t)}}{r} \exp\left\{-\int_t^T h_u du\right\} (p_T - w)\,. \end{aligned} \tag{38}$$

As $h \to \infty$, $V \to V^*$.

Fluctuations in a pre-producer's stock price.—A pre-producer may be publicly owned. While he experiences obsolescence of his ideas even before he starts to produce, he can be getting better off over time for a while in spite of failing to generate sales. If the firms are public, the value of its shares plus the value of its debt is V.[11] Differentiate (38) with respect to t and substitute from (18) into the resulting expression we get the pre-producer's Bellman equation:

$$\dot{V}_t = rV_t - h_t\left(V_t^* - V_t\right). \tag{39}$$

The disappointment in not having made the transition to production yet is proportional to $h\left(V^* - V\right)$. While the hazard is low (e.g., while it is zero), the pre-producer

[11] The presumption is that w is not the earnings that a manager of the firm could earn elsewhere, but that it is the per-unit-of-time value of the earnings of some hard assets what can, at any time, be sold for a salvage value of w/r. Thinking in this way simplifies the analysis.

gets better off as he waits for the hazard to rise. Still no dramatic upward price-swings are possible because $\dot{V} \leq rV$. A sufficient statistic for a pre-producer's intangible capital stock is the firm's age. In any case, it is impossible to get much movement in V without changes in h as the firm ages; V^* is given in (18) as a moving average of the industry's product price, and V^* is therefore a smoothed version of p. The V derives from V^* in (39) with h the only other input into its law of motion.

Stock-market capitalization.—If all the firms were publicly owned, the collective values of the firms in the industry would be

$$M_t \equiv q_t V_t^* + (n_t - q_t) V_t$$

This does not include firms that have exited – that have de-listed and collected the salvage value of w/r. In other words if we think of n as the collection of internet firms of which q are producers, M is like the total value of the Nasdaq given that all the firms are listed. Then when $\dot{n} < 0$, $|\dot{n}|$ would be the number de-listing. In the model all entry happens at the start so that $\dot{n}$ cannot be positive

Proposition 3

$$\dot{M} = -pq + rM + \dot{n}V. \tag{40}$$

Proof.

$$\begin{aligned}
\dot{M} &= q\left(\dot{V}^* - \dot{V}\right) + \dot{q}\left(V^* - V\right) + n\dot{V} + \dot{n}V \\
&= q\left(rV^* - p - rV + h\left(V^* - V\right)\right) + (n-q)\, h\left(V^* - V\right) + n\left(rV - h\left(V^* - V\right)\right) + \dot{n}V
\end{aligned}$$

since $\dot{q} = (n-q)\, h$, $\dot{V}^* = rV^* - p$, and $\dot{V} = rV - h\left(V^* - V\right)$. Therefore before exit begins,

$$\begin{aligned}
\dot{M} &= q\left(-p + (r+h)\left(V^* - V\right)\right) + (n-q)\, h\left(V^* - V\right) + n\left(rV - h\left(V^* - V\right)\right) + \dot{n}V \\
&= q\left(-p + r\left[V^* - V\right]\right) + nh\left(V^* - V\right) + n\left(rV - h\left(V^* - V\right)\right) + \dot{n}V \\
&= -pq + qr\left(V^* - V\right) + nrV + \dot{n}V \\
&= -pq + qrV^* + (n-q)\, rV + \dot{n}V \\
&= -pq + rM + \dot{n}V.
\end{aligned}$$

which proves the claim. ∎

On the region where no exit takes place, $\dot{n} = 0$. Elsewhere, $\dot{n} < 0$. Of more interest is the stock-price index

$$m = \frac{M}{n}$$

which is just the average value of the firms in the index. Let us define

$$\delta = \frac{pq}{n}$$

to be the dividend per firm (recall that marginal costs are zero). Then

Proposition 4

$$\dot{m} = -\delta + rm - \sigma \tag{41}$$

where

$$\sigma \equiv (m - V)\,\frac{\dot{n}}{n} \geq 0 \tag{42}$$

is the "survivorship bias".

Proof. Differentiating m and substituting from (40),

$$\begin{aligned}\dot{m} &= -\frac{pq}{n} + rm + \frac{\dot{n}}{n}V - m\frac{\dot{n}}{n} \\ &= -\delta + rm - (m - V)\,\frac{\dot{n}}{n}\end{aligned}$$

which proves (41). Next, the definition of M and m, and the fact that $V < V^*$ imply that $V < m$, so that (42) follows because $\dot{n} \leq 0$. ■

It is likely, however, that most pre-producers would be unlisted. In that case M would stand for the market value of all capital, including that which is privately held, valued at market prices, and m would be the index of a hypothetical portfolio comprising the survivors.

6 Planner's problem

There are no external effects here, and firms are negligible in size. The planner's solution should therefore coincide with equilibrium. The planner chooses the time-path of output and of the number of firms to maximize the discounted consumer's + producer's surplus. I will restrict the planner to non-increasing sequences n_t, which means that all entry is at the outset. As we noted earlier, this makes sense if h is increasing. Moreover, since producers are homogeneous, it will never be optimal for the planner to withdraw any producers from the industry. Only pre-producers will be withdrawn. The problem is

$$\max_{(n_t, q_t)_{t=0}^{\infty}} \left\{ \int_0^\infty e^{-rt} \left(\int_0^{q_t} D^{-1}(s)\, ds - w n_t \right) dt \right\}$$

subject to

$$\frac{dq}{dt} = h_t\,(n_t - q_t)\,; \qquad q\,(0) = 0$$

and to

$$\frac{dq}{dt} \geq 0 \quad \Leftrightarrow \quad q_t \leq n_t.$$

The Hamiltonian in terms of a current-value multiplier λ_t is

$$\mathbf{H}\,(n, q, \lambda, t) = e^{-rt} \left[\int_0^{q_t} D^{-1}(s)\, ds - w n_t + \lambda_t h_t\,(n_t - q_t) \right]$$

Except for the infinite horizon, this problem fits the Maximum Principle formulation as described in, e.g., Kamien and Schwartz (2000 Section 14). The correspondence becomes exact when F has a bounded support, which is to say when $F_{t_{\max}} = 1$ for some finite $t_{\max}$. The saddle point conditions are $\frac{\partial H}{\partial n} \leq 0$ and $\frac{\partial H}{\partial q} = e^{-rt}(\lambda_t' - r\lambda_t)$. They imply

$$\lambda_t h_t \leq w \tag{43}$$

and, except at points of discontinuity of n_t,

$$D^{-1}(q_t) - \lambda_t h_t = r\lambda_t - \lambda_t' \tag{44}$$

The solution for n_t is piecewise continuous and may have jumps, as the uniform example below suggests. For those values of t for which (43) holds as an equality, we have

$$\lambda_t = \frac{w}{h_t} \quad \text{and} \quad \lambda_t' = -\frac{w}{(h_t)^2} h_t'$$

which together with (44) imply (25).

TO BE CONTINUED

7 The production hazard and the exit hazard

The theory of this paper takes F and its hazard h as given. Empirically, Figure 4, e.g., shows T to be 30 months. The model predicts no continuous exit can take in the declining portion of the hazard. Therefore a value of T larger than 30 months would be better if the model is to fit data on shakeouts, which take place later in industry lifetimes.

7.1 The production hazard h.

Figure (4) reproduces Schoonhoven *et al*'s Figure 3. It portrays a non-parametric estimate $\hat{h}_t$ where t is the age of the firm since its founding, and it is measured in months. Note that at the mean of $t = 21$ months, the hazard rate is still rising, and the peak, at $t = 30$, is almost one standard deviation to the right of the mean. Thus for the semi-conductor firms, $h'(z) > 0$ is realistic. The model predicts that no pre-producer should have continued operations beyond the point $t = 30$ where the hazard peaks. The Appendix reports the data in greater detail. For automobile pre-producers, Carroll and Hannan (2000, p. 353) report a shape similar for the production hazard: It starts low in the first half year, rises rapidly through year six and then falls slowly.

Some caveats about Figure 4. First, it is probable that pre-production begins even before the firm is founded – before starting his firm, the founder has probably been tinkering in his garage for a while. Second, established firms sometimes diversify into

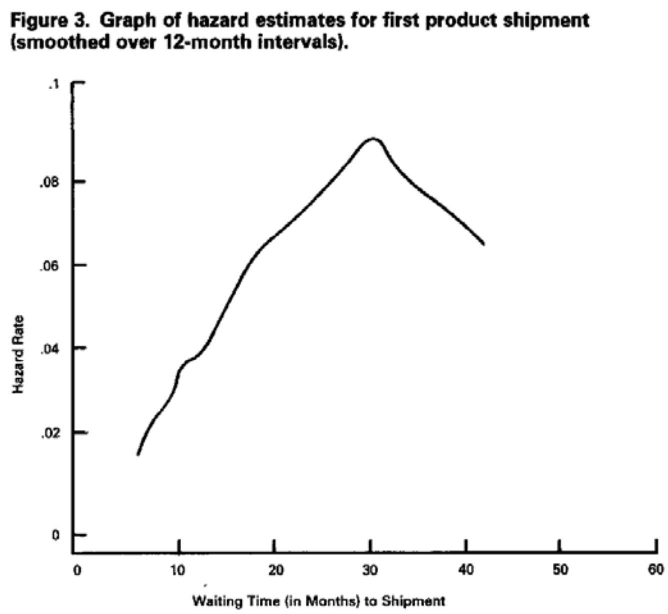


Figure 4: SCHOONHOVEN ET AL'S FIG. 3 : AN ESTIMATE OF THE PRODUCTION HAZARD $h(t)$.

new products, and then they are pre-producers only in part. Their activities are not covered in these data. The model applies to all activities that involve a sacrifice of earnings; Eisenhardt and Schoonhoven (1990) analyze the effects of various forms of the founder's prior experience on the performance of the firm.

7.2 The exit hazard

In the constant-hazard example the exit hazard is infinite at age T. In the bell-shaped case the hazard is positive on the interval $[\tau, T]$. Bruderl *et al.* (1992) present exit hazards for firms as a function of their ages since founding. It is plotted in figure 5. We see that exits are common even in the first 4 months, and that they peak in months 9-12.

Dividend payments.—The preproduction period is certainly one during which a firm does not generate a cash flow and, if it is publicly owned, it will not pay any dividends. Pre-dividend periods are considerably longer than pre-production periods. Even if we measure age as of the time that a firm first lists, it takes firms a long time before they pay dividends. A year after listing, only 28% of firms, and even 10 years after listing, only 51% of firms do (Pastor and Veronesi, forthcoming, Table 1).

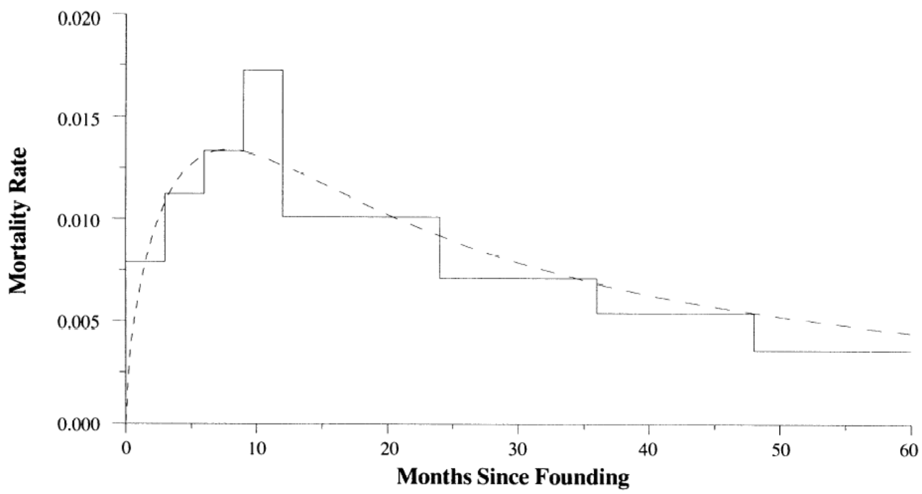


Figure 1. Mortality Rate for Newly Founded Business Organizations: Upper Bavaria, 1985 to 1990

Note: The step-function is the life-table rate estimator. The dashed curve is estimated using the proportional log-logistic rate model (without covariates). The number of cases is 1,794.

Figure 5: Bruderl et al.'s estimate of the exit hazard

8 Output and sales vs. age

Because pre-production is defined by the absence of sales, the most natural empirical relation to study is that between age and sales. Most work with plant-level and firm-level data from the U.S. uses employment or assets to measure firm size. Evans (1987), e.g., uses employment. But pre-producers can own assets and employ workers – it is *sales* that they do not have. Therefore evidence on the inputs is not directly relevant. The next sub-section gives three sorts of evidence:

1. Output and the age of an individual firm,
2. Median sales in a group of firms of the same age, and
3. Mean sales in group of firms of the same age.

For an individual firm, sales rise at the point when it becomes a producer, but thereafter they can only decline, because p_t declines. In a group of firms, however, the age-sales sales relation hinge on the elasticity of industry demand as well as on h_t, for reasons that the two time-paths of sales in Figure 1 differ from one another – see the end of Section 3.

Median output and sales vs. age.—In a group of firms of equal ages, median output and sales both must exhibit an S shape as a function of age. The distribution of start-up times is F. Let t_m be its median. I.e., $F_{t_m} = 1/2$. Then in the population

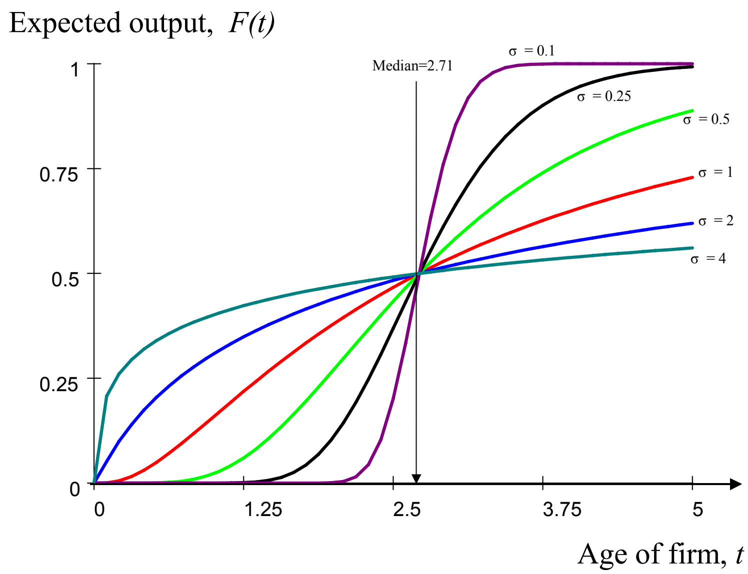


Figure 6: MEAN OUTPUT $F(t)$ AS A FUNCTION OF AGE

of firms of age t, median output jumps from zero to 1 at age $t = t_m$ and remains constant. Median sales jump from zero to p_t at date t_m, and thereafter they decline continuously. Therefore the plot of the time-path of the output of the median firm would look like the path in Figure 2, with the jump taking place at t_m. Since $F_t < 1$, the median should exceed the mean for $t \geq t_m$.

$$E(Y_t) = F_t$$

Mean output and sales vs. age.—In a group of firms of equal ages, whether *mean* output and sales are S shaped depends on the variance of the start-up times. I will show this by assuming F to be the log-normal distribution:

$$F_t = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{\ln t} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2} \right) dx$$

I simulate it for different values of σ, and I ignore any "survivorship" or "selection" bias induced by exit of some pre-producers. Let us set $\mu = 1$ so that the median is

$$t_m = e^1 = 2.71.$$

This will be held fixed in all the simulations. If all firms were the same (i.e., if $\sigma = 0$), then all of them would become productive at $t = 2.71$ and output would simply be zero until then, and one thereafter. We see, too, that for low values of σ, say less than 1/2, the S-shape is retained to an extent. For larger values of σ it disappears altogether.

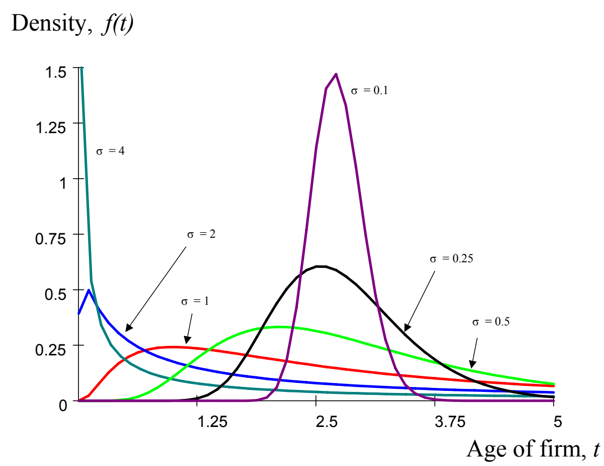
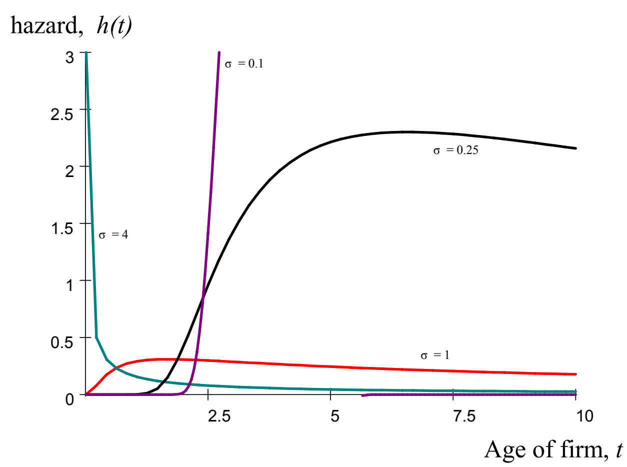


Figure 7: The various densities behind the plots in Fig 6

Figure 7 plots the densities

$$f_t = \frac{1}{\sqrt{2\pi}\sigma t} \exp\left(-\frac{(\ln t - \mu)^2}{2\sigma^2}\right)$$

associated with all these curves. The colors of the two sets of curves correspond.



Hazard rates for four different values of σ

The hazard rate $h_t = f_t / (1 - F_t)$, and four of the them are plotted in the next figure. The hazard for $\sigma = 1$ is the hazard that corresponds most closely to the hazard reported in figure 4.

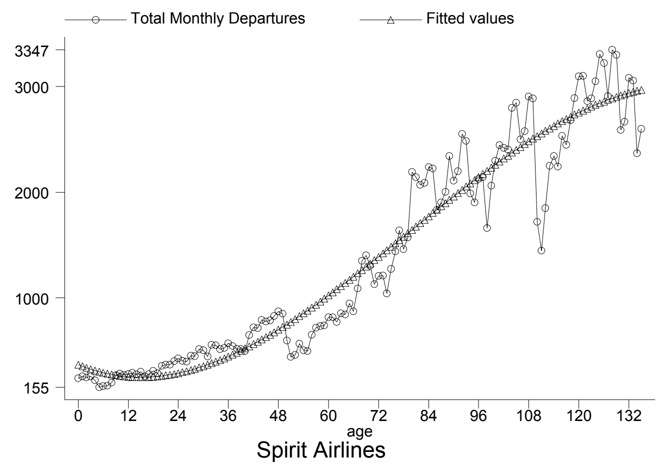


Figure 8: Spirit Airlines' number of departures per month as a function of its age in months

8.1 Evidence on sales vs. age

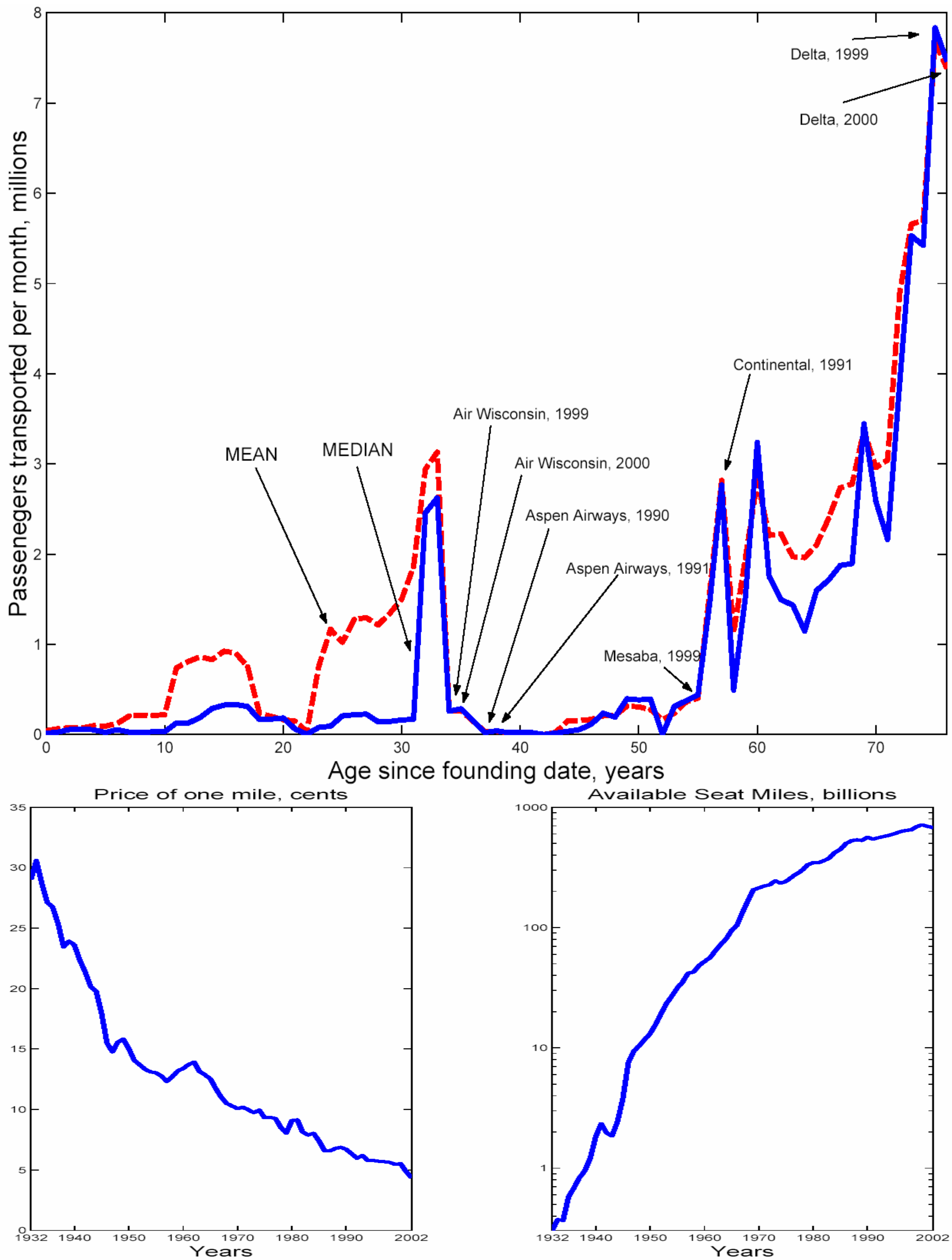
This section reports evidence from various places about the presence of something we may call a pre-production period. A pre-producer waits for his sales to "take off". Sticking with the metaphor of a flying object, let us start with an age-sales plot for an up-and-coming airline.

8.1.1 Output and age: Airlines

Spirit Airlines was founded in May 1992. Today they serve 16 destinations with 120 flights daily flight departures. Spirit's fleet currently consists of 32 MD-80 aircraft and it currently has 2,700 employees. It is the largest privately-held airline. Figure 8 shows the number of flights per month on the vertical axis and the airline's age in months. The graph also reports the fitted cubic which has a pronounced shape, bottoming out at 14 months and an inflection point (which denotes the fastest absolute growth in sales) at about 72 months – i.e., 6 years.

We have other data on the age and output of airlines for the period 1990-2003 which we truncate at 2000 to eliminate the 9/11 effect on travel. The age of an airline is time elapsed since it was founded. Names and ages of airlines are listed in Figures 16 and 17, along with their year-2000 output if they have survived, or their date of exit if they have failed.

Data on output are monthly (4850 monthly observations). In the plot they are averaged over a year. The averages are calculated both over time and across firms. So a firm that hasn't exited contributes to the mean and median of exactly 11 years, each year of its age times the years of the sample, 11. The mean is then calculated on monthly output. So one point in the plot is the mean monthly output of a carrier



Delta, 1999
Delta, 2000
Continental, 1991
Air Wisconsin, 1999
Air Wisconsin, 2000
Aspen Airways, 1990
Aspen Airways, 1991
Mesaba, 1999
MEAN
MEDIAN
Passenegers transported per month, millions
Age since founding date, years
Price of one mile, cents
Years
Available Seat Miles, billions
Years

U.S. Airlines

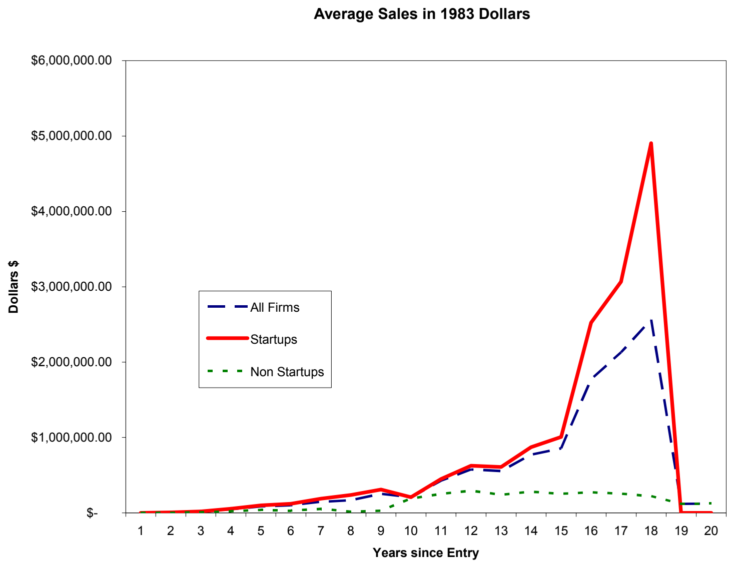


Figure 9: SALES PER FIRM AND FIRM AGE IN DISK-DRIVE MANUFACTURE – FILSON AND GRETZ (2004)

of age t in years. The relation between mean output and airline age is plotted in the top panel of the Figure on U.S. Airlines. The bottom panel plots price per seat and annual capacity. When the mean and median coincide (as they do in 8 cases; at ages 34, 35, 37, 38 55, 57, 75 and 76), it not simply a firm, but a firm-year pair. For example, age 76 is the mean monthly output of delta in 2000, and no other airline of with that age exists in the sample. A few of these are labeled.

8.1.2 Sales and age: Disk drives

In Filson and Gretz (2004), a sample of rigid disk-drive firms shows a pronounced S-shape as a function of the age of the firm. This is reported in Figure 9. “Age” means years since entry into the disk-drive business. The data are in thousands. The scale on the y axis should be billions not millions. The plot pools firms from many different cohorts. The S shape holds up until the top age of 19 years. The dip at the end of the series occurs because the sales data stop in 1996 and the firms that grew largest entered in 1979 and later (most were involved in pioneering 5.25" drives, used in personal computers, which began to really take off in the early 1980’s). Only one firm in the sample reached an age greater than 17 years before 1996, and it was one of the less successful entrants.

8.1.3 Sales and age: Spanish firms

Figure 10 presents plots for monthly sales as a function of the firm's age measured in months. More plots for annual data and a description of the data are in the Appendix. There I also report plots for a small sample of German firms. Larger samples of firms are available for the U.K. and analyzed by Cuñat (2002). The following plots pool firms from different cohorts.

8.1.4 Venture-capital backed companies

The following two studies provide information about a company's status at the time of VC investment in it. We also know something about the age of these companies. Gompers and Lerner (1999, table 5.2) report that in their sample the median company age was 3 years. Of these, only 53% had sales and only 7.6% were profitable. Thus it would seem that it takes the median firm about 3 years to generate sales. Kaplan and Strömberg (2003) report that about half of the investment rounds were "pre-revenue rounds," i.e., investments in firms that had no sales. And Kaplan and Strömberg (2002 Table 4) show VC's projecting that after VC investment the firm will take at least 2 years to catch up with the rest of the industry in terms of its profitability.

8.1.5 Time-to-build studies

One way to see z is as time to build. The 30-month hazard mode discussed above is not much higher estimates of time to completion of projects that entail spending on plant and equipment (Mayer 1960). Moreover, the shape of the hazard $\hat{h}_t$ is similar to the time profile expenditures on the typical investment project of incumbent firms. For a collection of projects of automobile firms Krainer (1968) finds that such expenditures peak somewhere between 9 months and 2 years. In each of 25 investment projects, cumulative expenditures were S-shaped.. He fits a logistic curve to it. Koeva (2003) reports time-to-build delays by two-digit sector. Of the 106 projects undertaken by large firms only 10 of these projects were delayed or abandoned. Contrast that with the 89 percent abandonment rate among automobile pre-producers reported by Carroll and Hannan (2000, p. 347).

9 Theoretical literature

The model resembles Loury (1979) and Lee and Wilde (1980) where inventions arrive at a random dates but where the first inventor gets the whole market. I add a continuum of players but remove the winner-take-all assumption by constraining each firm's capacity, so that early producers do drive some but not all of the laggards out of the market, and the process takes time. The model also relates to Filson and Franco (2000) and Irigoyen (2003) where the pre-production period is a stint with an employer who pays less but who in return trains his workers. In Pissarides (2000), an

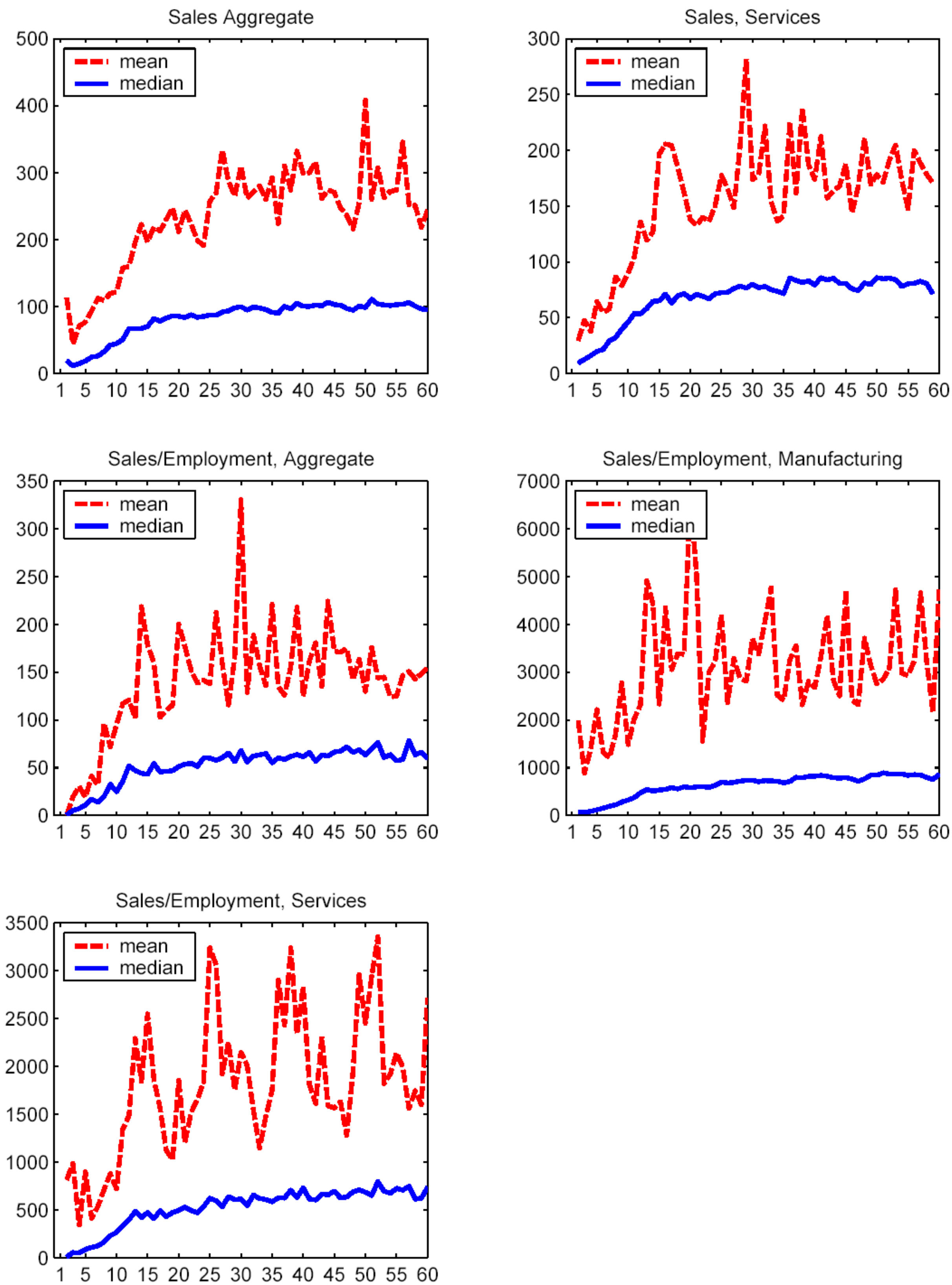


Figure 10: Monthly Sales and Sales/Employment ratio, in millions of 1995 Euros.

entering firm is a pre-producer until it meets a worker. Other ways of endogenizing the pre-production period are studied in Jovanovic and Rousseau (2001) and Jovanovic (2003).

Formally, the model is related to several in the literature. Here is an incomplete list

1. This firm-specific parameter z reveals itself – in part gradually – to pre-producers in much the same way as the firm's efficiency revealed itself to firms in the model in Jovanovic (1982). In that model, the closest thing to pre-producers are the low-output firms which have unusually high production costs

2. In the Mortensen-Pissarides type of model an unfilled vacancy can be viewed as a pre-producing firm. Pissarides ch. 1 and AER 85 – after a favorable shock, many vacancies come in. But then the falling u/v ratio plays the role that falling p_t does here, and it can result in the discouragement of some vacancies.

3. The homogeneous firm version is similar to Lucas (1988, Sec. 5). The inelastic case is that of "immiserizing growth". The alternative activity (which nets w per period) is the other technology that entails no LBD. A non-monotone sales relation emerges in Chari and Hopenhayn (1990)

We have sidestepped some important issues. (i) *Monopoly power*: if we were dealing with small numbers of firms, the answer would have to be "yes" because the market with individual differences in fortunes would produce more market power – something that Demsetz (1973) stressed; (ii) *Finance constraints*: A pre-producer would starve if he could not borrow the money needed to keep him going. Formally, a denial of essential funds could prompt exit even when $V > w/r$. (iii) *Ex-ante heterogeneity*: Pre-producers may be different *ex-ante*; Appendix 2 treats this case briefly. .

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10 Appendix 1: Existence of the equilibrium for bell-shaped hazards – Notes

Here I derive conditions that will be sufficient for an equilibrium with exit on $[0, T]$, for bell-shaped hazards that peak at T.

If h is bell shaped, $h' > 0$ for $t < T$ and $h' = 0$ at date T...... Let

$$\psi_t = \left[1 + \frac{1}{h_t}\left(r + \frac{h_t'}{h_t}\right)\right] w$$

This is the solution for the price path that guarantees indifference to exit everywhere, including at $t = T$ because there $h_T' = 0$.

The first condition is that ψ_t must be decreasing in t:

$$\psi_t' = -\frac{w}{h^2}\left(r + \frac{2h'}{h}\right) + \frac{wh''}{h^2}$$

Therefore $h'' < 0$ is sufficient.[12]

THIS PARAGRAPH TO BE RE-WRITTEN Suppose that $D(0) > \psi_0$. Then n_0 firms can come in to produce a date-τ level of output $q_\tau = n_0 F_\tau$ satisfying

$$\psi_\tau = D(n_0 F_\tau). \tag{45}$$

Eq. (45) has two unknowns: τ and n_0. However, we also have the free-entry condition

$$V_0 = k + \frac{w}{r}$$

Thereafter exit begins and continues until date T when all the pre-producers are gone. Therefore

$$q_t = D^{-1}(\psi_t) \text{ for } t \in [\tau, T]$$

which is an increasing function because ψ_t is decreasing. Now since there is no new entry, any increase in output must come from a flow of pre-producers becoming producers. The size of that flow depends on the existing stock of pre-producers. There must always be enough pre-producers left to allow output to keep increasing. We now look into the conditions that guarantee this.

[12] But it is not necessary, as, e.g., when z is distributed uniformly on the unit interval so that $F(t) = t$, The hazard, $h = 1/(1-t)$ is convex and yet $\psi_t = (2 + (1-t) r) w$ declines with t.

Let y be the number of these pre-producers. But can the remaining pre-producers sustain an increase in output that is needed? Since

$$D'(q_t)\frac{dq}{dt} = \psi'_t,$$

we have

$$\frac{dq}{dt} = \frac{1}{D'\left(D^{-1}[\psi_t]\right)}\psi'_t \tag{46}$$

But since no one that becomes a producer ever exits,

$$\frac{dq}{dt} = h_t y_t.$$

which means that

$$\begin{aligned} y_t &= \frac{1}{D'\left(D^{-1}[\psi_t]\right)}\frac{\psi'_t}{h_t} \\ &\equiv \xi_t \end{aligned}$$

This number ξ_t is the "required" number of pre-producers that it takes to get output to keep rising at just the rate needed to keep the existing pre-producers indifferent between staying and exiting.

But there is no entry of pre-producers after date $t = 0$. Therefore this "required" number, ξ_t must never exceed the actual number of pre-producers. If this happened for any $t \in [0, T]$, we could not have an equilibrium of the sort described above. be decreasing faster at date t than the outflow that would occur because of the conversion of pre-producers to production mode. That is, we must have

$$\frac{d\xi}{dt} < -h_t\xi_t$$

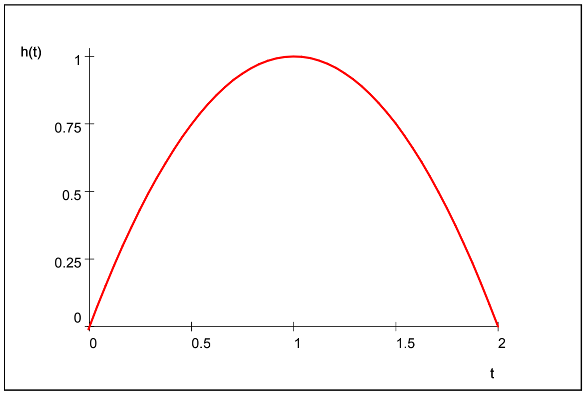
That is,

$$d\ln\xi_t < -h_t$$

The required number of pre-producers must be shrinking faster than the rate of outflow of pre-producers, h_t. This is a condition that must be checked for all $t \in [0, T]$.

The general question is whether there are functions $D()$ and h that will meet all these conditions. The uniform distribution does not have a maximum for h_t, does not have the property that there exists a T at which $h'_T = 0$, and therefore does not work. One example that does work is

$$h_t = 1 - (1-t)^2$$



A PLOT OF $h_t = 1 - (1-t)^2$

which is maximized at $T = 1$. Then the exit region should be $[0, 1]$. Either

$$D(q) = A - bq$$

or the unit elastic

$$D(q) = \frac{A}{q}$$

should work.

11 Appendix 2: Unequal but known waiting times, with firms in fixed supply

There are reasons to expect some differences in z's that are known beforehand. The background of the founder – the founder's prior work experience, e.g., and, especially, prior experience start-up companies – are significant predictors of performance.

In order to get a well-defined upward sloping supply curve of entrepreneurs, we must limit their number. Let the total mass of potential firms be n_0, a number that is now exogenous. We seek a marginal firm equilibrium where the best (i.e., lowest-z) firms draw rents on their superior quality. Let z_m be the highest-z firm that enters. Figure 11 illustrates this.

As in the earlier models, all entry occurs at date zero, and here we assume that $k = 0$. Since no exit occurs, the time path of output is

$$q(t, z_m) = \min(n_0 F_t, n_0 F[z_m]),$$

which means that industry price is

$$p(t, z_m) = D(q[t, z_m]).$$

The marginal entrant must be indifferent between entering and staying out:

$$\frac{w}{r} = e^{-rz_m} \frac{1}{r} D(n_0 F(z_m)), \tag{47}$$

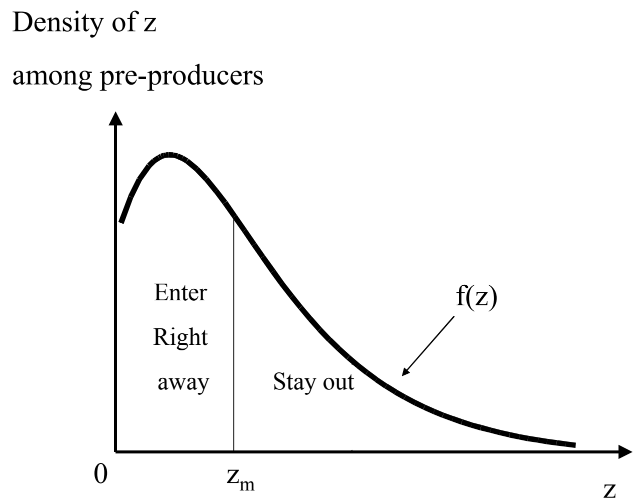


Figure 11: THE MARGINAL ENTRANT EQUILIBRIUM z_m

so that

$$p = e^{rz_m} w. \tag{48}$$

The low-z entrepreneurs draw predictable rents on their ability, and the marginal firm just breaks even.

EQUILIBRIUM is the pair of numbers (p, z_m) solving (47) and (48). Note

1. The similarity between (3) and (48). In (3) it is the common z that matters, whereas in (48) it is the marginal z,

2. No exit takes place, though industry output now grows smoothly. Once again we cannot explain the temporary presence of firms that have never sold and will never sell any output.

The time path of prices is drawn in Figure 12. This model has implications that are almost identical to one in which firms face a firm-specific dollar cost of entry $\phi(z) = \frac{1}{r}(e^{rz} - 1)$. The only difference is that in such a model output would be $n_0 F(z_m)$ from the outset, and p would at once be $D(n_0 F[z_m])$.

A variety of evidence shows that prior differences matter. Schoonhoven *et al.* (1990 Table 3) find that the founder's prior experience with other start-ups reduces z. Agarwal and Bayus (2003) find that *de alio* entrants are more likely to survive, and a similar finding is implicit in Table 6.4 of Carroll and Hannan (2000). This suggests, e.g., that lateral entrants have spent a longer time in preproduction than *de novo* entrants. Carroll et al (1996) find that lateral entrants have initial advantages over *de novo* entrants- further we find that *de novo* entrants with pre-production periods initially enjoy survival advantages over *de novo* entrants without such a period. More

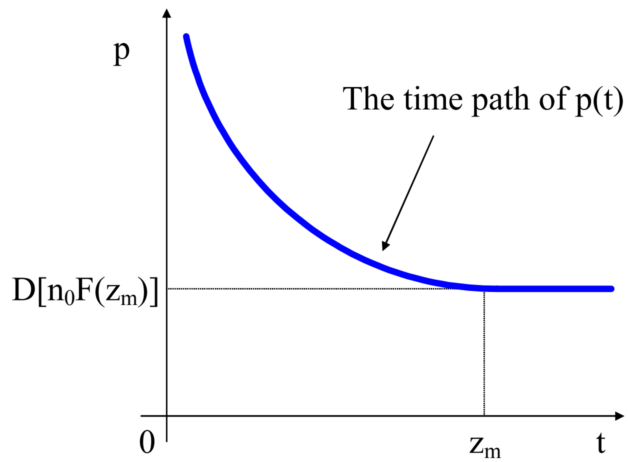


Figure 12: A PLOT OF THE FUNCTION $p(t)$ WHEN FIRMS ARE EX-ANTE DIFFERENT

general evidence that prior differences matter is in Carneiro *et al.* (2003, pp. 398-402) find that in the context of schooling decisions unmeasured prior differences in ability determine post-schooling earnings differentials.

12 Data

12.1 Spanish firms – annual data

The Database: Sabe (Sistema de análisis de balances españoles). This database contains the financial accounts for all Spanish firms with a minimum annual invoicing of 100 million pesetas, during the period 1989-2001 – about 734,000 US dollars. Therefore all firms must have some sales to be included. Although the limit is not a small amount and would disqualify many small businesses in the US, and would certainly eliminate all that did not sell anything. This is not so much a problem because we still see an S-shape in the monthly data. Presumably it would be even more S-shaped if the smaller-selling firms were included.

The variables used are: Total sales (account number 727), Total number of employees (n94). To deflate sales, we used the Deflator for Total Domestic Demand (Source: OCDE Economic Outlook). Figures 13 and 14 present plots for selected industries at various levels of aggregation. A web-site describing the SIC codes is http://www.osha.gov/cgi-bin/sic/sicser5.

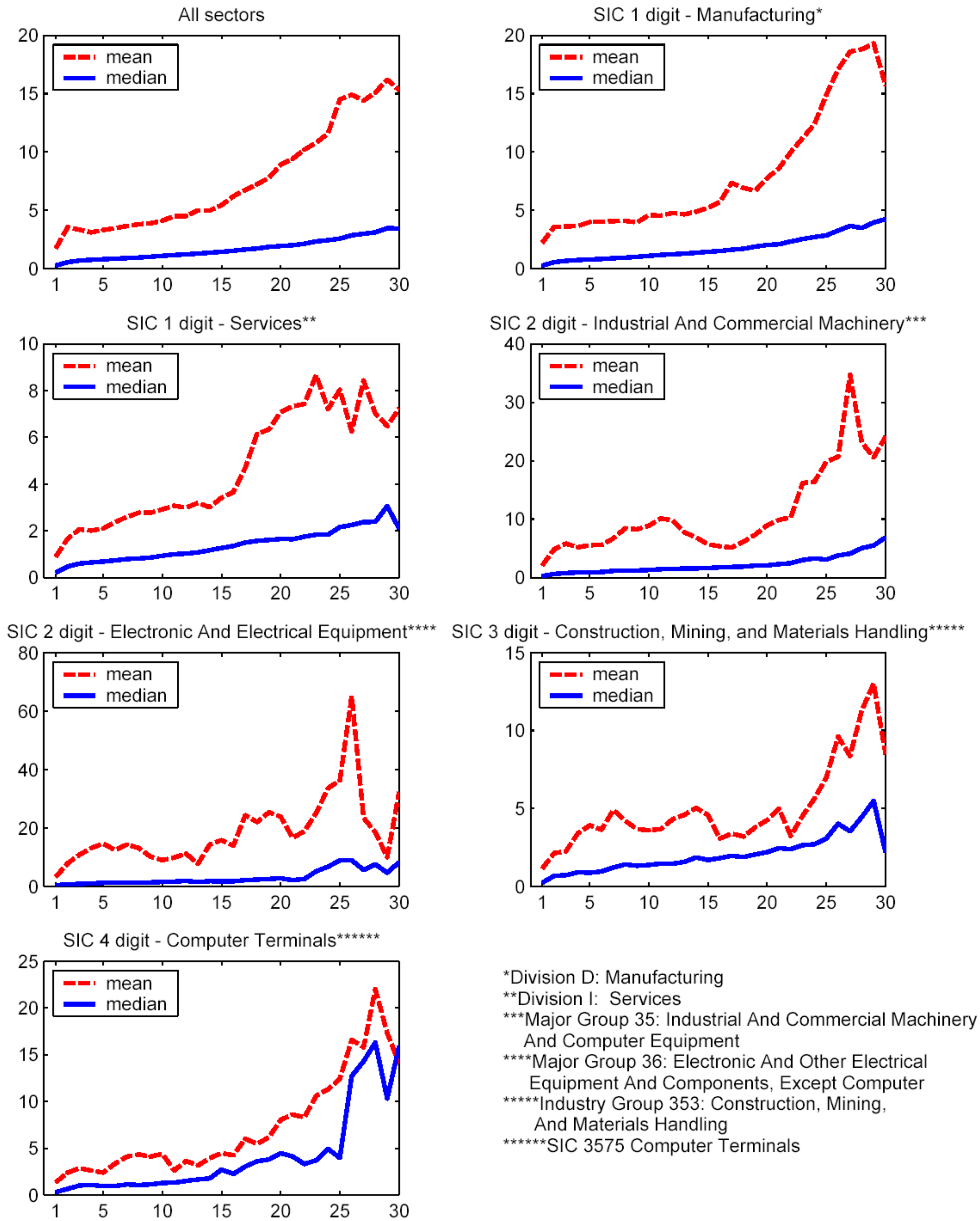
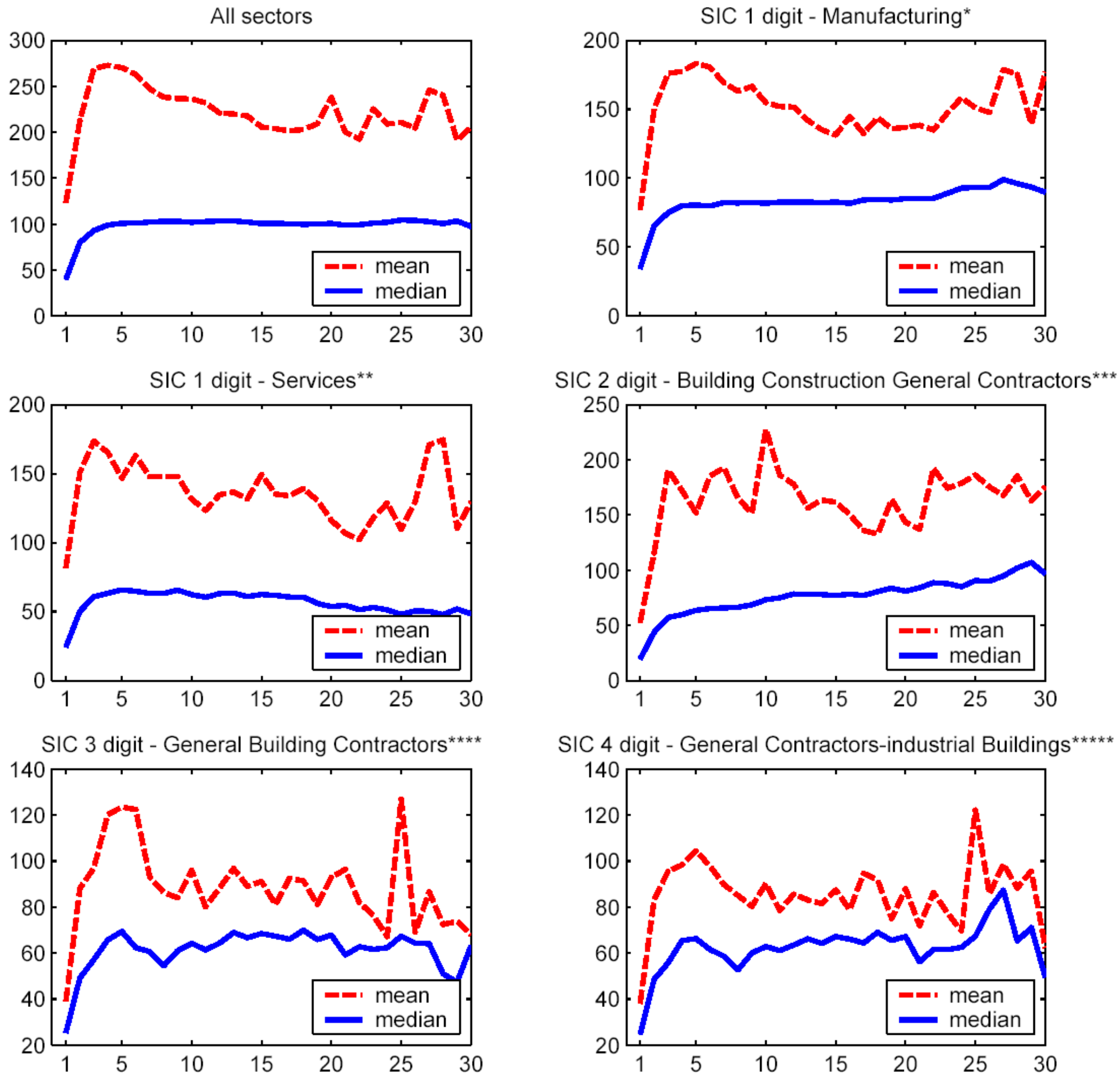


Figure 13: Spanish firms: annual sales, millions of 1995 Euros.



*Division D: Manufacturing
**Division I: Services
***Major Group 15: Building Construction, General Contractors And Operative Builders
****Industry Group 154: General Building, Contractors-nonresidential
*****SIC 1541 General Contractors- industrial Buildings And Warehouses

Figure 14: Spanish firms: Sales/Employment ratio, in thousand of 1995 Euros.

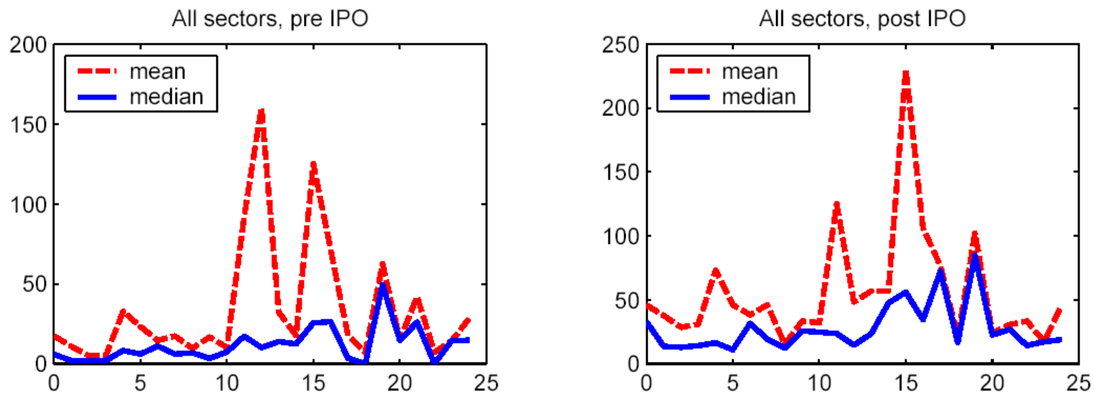


Figure 15: German firms: Sales, millions of Euros

12.2 German firms

Figure 15 reports annual data for German firms. The original sample contained 273 observations. Firms with age to IPO larger than 24 were discarded since there was just one observation per year. This procedure reduced the sample to 260 firms. The data are described in Audretsch and Lehmann (2003).

12.3 Plot 1 – The U.S. automobile industry – notes on data sources

The top two panels of the opening plot are scanned replicas of figures in the unpublished version of Carroll, Bigelow, Seidel and Tsai (1996), which also includes Hannan as a co-author. The bottom two panels use data from that same study provided by G. Carroll. The middle two panels are from data underlying Figure 1 of Jovanovic and Rousseau (2002) and a detailed description of the data is supplied there. In brief, Motor vehicle prices for 1913-40 are annual averages of monthly wholesale prices of passenger vehicles from the National Bureau of Economic Research (MacroHistory Database, series m04180a for 1913-27, series m04180b for 1928-40, http://www.nber.org). From 1941-47, they are wholesale prices of motor vehicles and equipment from Historical Statistics (series E38, p. 199), and from 1948-2000 they are producer prices of motor vehicles from the Bureau of Labor Statistics (http://www.bls.gov).The price and quantity indexes try to correct for quality change. To approximate prices from 1901-1913, we extrapolate assuming constant growth and the average annual growth rate observed from 1913-24. We then join the various components to form an overall price index, and set it to equal 1000 in the first year of the sample (i.e., 1901).

12.4 The U.S. Aircraft industry

Price paid by revenue passengers for one mile on total available seat miles come from `http://www.airlines.org/econ/d.aspx?nid=1028`, the web-site of the air transport association. The price and quantity data are from 1932 to 2002 and for domestic routes only. The founding dates come from `http://www.aerofiles.com/airlines-am.html`.

CARRIER NAME	PASSENGERS IN 2000	YEAR FOUNDED	EXIT
Accessair Holdings	0	1998	1999m11
Air South, Inc.	0	1967	1997m7
Air Wisconsin Airlines Corp	2,814,480	1965	
Air Wisconsin, Inc.	0	1965	1993m12
Airtran Airways Corporation	5,535,905	1994	
Alaska Airlines, Inc.	9,228,335	1932	
Aloha Airlines, Inc.	3,801,161	1946	
America West Airlines, Inc.	14,400,000	1983	
American Airlines, Inc.	49,900,000	1930	
American Eagle Airlines,inc	7,969,336	1984	
American Trans Air, Inc.	4,443,834	1981	
Amerijet International	0	1990	2000m12
Arrow Air, Inc.	0	1947	2000m12
Aspen Airways, Inc.	0	1953	1991m4
Atlantic Southeast Airlines	4,395,683	1979	
Atlas Air, Inc.	0	1992	
Av Atlantic	0	1990	1996m8
Braniff Int'l Airlines, Inc	0	1927	1992m5
Buffalo Airways, Inc.	0	1984	1996m2
Business Express	0	1981	1996m3
Casino Express	159,901	1989	
Challenge Air Cargo, Inc.	0	1987	
Chicago Express	71,009	1993	
Comair, Inc.	3,862,239	1977	
Continental Air Lines, Inc.	26,700,000	1934	
DHL Airways	0	1992	
Delta Air Lines, Inc.	72,100,000	1924	
Eastern Air Lines, Inc.	0	1927	1991m1
Emery Worldwide Airlines	0	1978	2000m11
Empire Airlines, Inc.	0	1975	1994m6
Federal Express Corporation	0	1973	1997m8
Flagship Airlines, Inc.	0	1988	1998m3
Florida West Airlines, Inc.	0	1985	1997m3
Frontier Airlines, Inc.	2,203,041	1994	
Gemini Air Cargo Airways	0	1995	
Great American Airways	0	1979	1996m11
Hawaiian Airlines, Inc.	4,286,880	1929	
Horizon Air	3,204,614	1981	
Independent Air, Inc.	0	1988	1990m7
International Cargo Xpress	0	1992	1994m6

Figure 16: U.S. Airline Carriers – Part 1

CARRIER NAME	PASSENGERS IN 2000	YEAR FOUNDED	EXIT
Jetblue Airways	821,880	2000	
Kitty Hawk Aircargo	0	1978	1999m3
Kiwi International	0	1992	1999m1
Legend Airlines	68,542	2000	2000m10
Markair, Inc.	0	1947	1995m8
Mesa Airlines, Inc.	0	1980	1997m6
Mesaba Airlines	4,448,564	1944	
Midway Airlines, Inc.	2,042,307	1980	
Midwest Express Airlines	1,633,344	1969	
Morris Air Corporation	0	1992	1994m10
National Airlines	1,513,276	1934	
Nations Air Express, Inc.	0	1995	1999m2
North American Airlines	60,763	1982	
Northwest Airlines, Inc.	35,500,000	1926	
Pacific Interstate Airlines	0	1985	1991m6
Pan American Airways Corp.	114,963	1999	
Pan American World Airways	0	1927	1999m7
Polar Air Cargo Airways	0	1994	2000m9
Pro Air, Inc.	242,853	1997	2000m9
Reeve Aleutian Airways, Inc	36,049	1932	2000m11
Reno Air, Inc.	0	1990	1999m8
Ryan International Airlines	309	1975	
Simmons Airlines	0	1979	1998m3
Southeast Airlines	9,219	1958	2000m6
Southern Air Transport, Inc	0	1929	1998m6
Southwest Airlines, Co.	59,100,000	1967	
Spirit Air Lines	2,024,940	1992	
Sun Country Airlines	1,479,503	1986	
Sun Pacific International	0	1996	1999m2
Tower Air, Inc.	111,404	1990	2000m8
Tradewinds Airlines	0	1990	1999m2
Trans Continental Airlines	0	1985	1998m11
Trans States Airlines	1,267,871	1989	
Trans World Airlines, Inc.	18,300,000	1929	
Tristar Airlines, Inc.	0	1995	1996m8
Trump Shuttle	0	1989	1992m3
USAirways	41,706,336	1979	
UltrAir	0	1992	1994m7
United Air Lines, Inc.	53,000,000	1931	
Vanguard Airlines, Inc.	1,351,230	1994	
Westair Airlines, Inc.	0	1990	1993m6
World Airways, Inc.	2,892	1948	

Figure 17: U.S. Airline Carriers – Part 2