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VINTAGE ORGANIZATION CAPITAL

Boyan Jovanovic
Peter L. Rousseau

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ABSTRACT

We study 114 years of U.S. stock market data and find

- That there are large cohort effects in stock prices, effects that we label "organization capital,"
- That cohort effects grew at a rate of 1.75% per year,
- That the debt-equity ratio of all vintages declined,
- That three big technological waves took place: electricity (1895-1930), a "World War II" wave (1945-1970), and information technology (1971-), and
- That organization capital tends to grow fastest during the second half of a technological wave.

Boyan Jovanovic
Department of Economics
University of Chicago
1126 E. 59th St.
Chicago, IL 60637
and NBER
(773)702-7147
bjovanov@uchicago.edu

Peter L. Rousseau
Department of Economics
Vanderbilt University
Box 1819, Station B
Nashville, TN 37235
and NBER
(615)343-2466
peter.l.rousseau@vanderbilt.edu

Vintage Organization Capital: 1885-1998

Boyan Jovanovic and Peter L. Rousseau*

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1 Introduction

Among the firms that now list on the stock exchange one can find more than one hundred vintages of firms. Most have entered the market since the second world war, but some date back to the 19th century. Figure 1 provides an accounting of the value, in 1998, of all firms that were then listed on the three major U.S. stock exchanges: the NYSE, the AMEX and the NASDAQ.[1] The solid line accounts for the total 1998 value of the stocks by year of their first listing.[2] An OLS regression of its logarithm on a constant and linear time trend indicates annual growth of 4.4 percent.

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[1]We extended the CRSP stock files backward from their 1925 starting year by collecting year-end observations from 1885 to 1925 for all common stocks traded on the NYSE. Prices and par values are from the *The Commercial and Financial Chronicle,* which is also the source of firm-level data for the price indexes reported in the Cowles Commission's *Common Stock Prices Indexes (1938).* We obtained firm book capitalizations from *Bradstreet's*, *The New York Times*, and *The Annalist*. The resulting dataset defines our sample of 21,516 firms, and though limited to annual observations, actually includes more common stocks than the CRSP files in 1925. As such, the dataset complements others that have begun to build a more complete view of securities prices in other markets for the pre-CRSP period. See, for example, Rousseau (1999, 2000) on Boston's equity market.

[2]AMEX firms enter CRSP in 1962 and NASDAQ firms in 1972. Since NASDAQ firms traded over-the-counter before 1972 and AMEX's predecessor (the New York Curb Exchange) dates back to at least 1908, we adjust the entering capital in 1962 and 1972 by re-assigning most of it to an approximation of the "true" entry years. We do this by using various issues of Standard and Poor's *Stock Reports* and *Stock Market Encyclopedia* to obtain incorporation years for 117 of the 274 surviving NASDAQ firms that entered CRSP in 1972 and for 907 of the 5,213 firms that entered NASDAQ after 1972. We then use the sample distribution of differences between incorporation and listing years of the post-1972 entrants to assign the 1972 firms into proper "IPO" years, starting with 1971 and re-scaling the distribution of post-1972 differences to include only the relevant distances. In 1971, for example, this procedure implies taking the percentages associated with listing lags of 0 years and 1 year, re-scaling them to sum to unity, and applying the re-scaled percentages of the share

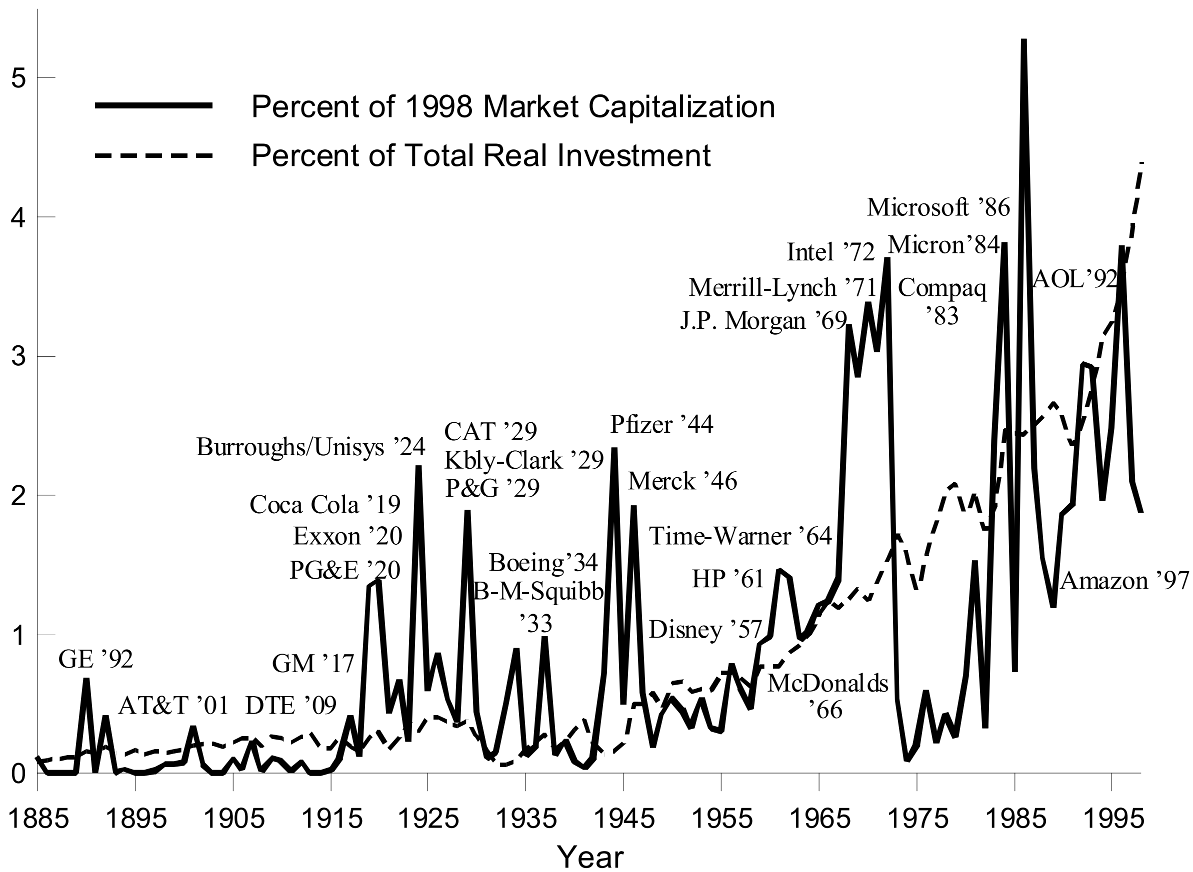

Figure 1: Annual U.S. gross investment and the 1998 value of all listed firms by year of listing.

Some vintages retain a strong presence in 1998, even per unit of investment. The dashed line in Figure 1 accounts for all cumulative real investment by the vintage of that investment.[3] Relative to that investment, the '50s and even the '60s, which saw the Dow and the S&P 500 indexes do very well and which some economists refer to

of firms incorporated in 1971 to the 1971 and 1972 entry years. We repeat the procedure for each year from 1970 back to 1885, re-scaling the post-1972 sample density each time to include only the relevant year ranges. The result is a vector of percentages of the 1972 NASDAQ entrants that should be assigned to each prior year. Even though 13.4% of the surviving 1998 capital can be attributed to firms that entered CRSP in 1972, not all of this capital entered via NASDAQ. We therefore assume that the average percentage of 1998 capital attributed to the years 1969-1971 (1.7%) entered CRSP in 1972 through NYSE or AMEX, leaving the difference of 11.7% to re-distribute. We use a similar procedure for the 1962 AMEX entrants.

[3]The cumulative investment series is private domestic investment from Kendrick (1961), table A-IIa for 1885-1953, joined with estimates for more recent years from the National Income and Product Accounts.

as a golden age – did not do as well as the 1920's.

In a one-sector world in which every firm financed its startup investment with a stock issue and then simply kept up its capital and paid for all parts and maintenance out of its profits, each firm's current value would be proportional to its initial investment, and the dashed lines and the solid lines would coincide. Why, then, does the solid line deviate from the dashed line? Why, for example, do the vintage-'20s firms account for relatively more stock-market value than they do for gross investment? Several explanations come to mind:

1. *Technology*: The entrants of the 1920's came in with technologies and products that were better and therefore either (*a*) accounted for a bigger-than-average share of all '20s investment, (*b*) delivered a higher return per unit of investment or (*c*) invested more than other firms in subsequent decades. The state of technology prevailing at the firm's birth affects that firm for a long time, sort of like the weather affects a vintage of wine; some vintages of wine are better than others, and the same seems to be true of firms.

2. *Mergers and spinoffs*: The dashed line is aggregate investment, not the investment of entrants (on which we do not have data). The entrants of the 1920's were, perhaps, not new firms embodying new investment but, rather, existing firms that split or that merged with other firms and re-listed under new names, or privately held firms that went public in the '20s. We accordingly adjust Figure 1 for mergers to the extent that is possible with available data.[4] Some mergers may embody a decision by incumbents to redirect investment and redeploy old capital to new uses. Such mergers arise *because* of technological change. Others may arise because of changes in antitrust law or its interpretation. Either way, a new listing may be a pre-'20s entity disguised as a member of the '20s cohort.[5]

[4]The merger adjustment uses several sources. CRSP itself identifies 7,455 firms that exited the database by merger between 1926 and 1998, but links only 3,488 (46.8%) of them to acquirers. Our examination of the 2000 Edition of Financial Information Inc.'s *Directory of Obsolete Securities* and every issue of Predicasts Inc.'s *F&S Index of Corporate Change* between 1969 and 1989 uncovered the acquirers for 3,646 (91.9%) of these unlinked mergers, 1803 of which turned out to be CRSP firms. We also recorded all mergers from 1895 to 1930 in the manufacturing and mining sectors from the original worksheets underlying Nelson (1959) and collected information on mergers from 1885 to 1894 from the financial news section of weekly issues of the *Commercial and Financial Chronicle.* We then recursively traced backward the merger history of every 1998 CRSP survivor and its targets, apportioning the 1998 capital of the survivor to its own entry year and those of its merger partners using the share of combined market value attributable to each in the year immediately preceding the merger. The process of adjusting Figure 1 ended up involving 5,422 mergers.

[5]An analysis of mergers in the manufacturing and mining sectors in the '20s, however, suggests that capital brought into the market by entering firms shortly after a merger cannot account for very much of the entry in Figure 1. We reached this conclusion after examining all 2,701 mergers recorded for the '20s in the worksheets underlying Nelson (1959). Many mergers involved a single acquirer procuring multiple targets in the course of consolidation. We included the value of acquirers

3. *Financing.* The entrants of the 1920's may have financed a higher-than-average share of their own investment by issuing shares, or they later (e.g., in the 1990's) bought back more of their debt or retained more earnings than other firms did.

4. *Bubbles*: The '20s cohort may be overvalued, as may be the high tech stocks of the 1990s, while other vintages may be undervalued.

5. *Market power, monitoring*: The '20s cohort may be in markets that are less competitive or in activities for which shareholders can monitor management more easily.

Only the first explanation invokes the quality of the entering firms. We build a model in which differences between the solid and dashed lines in Figure 1 arise because of factors 1(a), and 1(b) alone – a quality explanation as one would naturally use with vintage wines, for instance. Implicitly, we appeal to the market power that a firm derives from the patents that it may own on its inventions and products. In the data work, we control for factors 2 and 3. We believe that factor 4 does not contaminate our estimates because differences among values of vintages have been highly stable over time (see Figure A1 in the appendix). That is, if a firm today is overvalued relative to its fundamentals, it has *always* been overvalued, and that seems highly improbable. Finally,we have not tried to see the products invented in the 1920's are more sheltered from competition than other generations of products, but on the face of it the idea seems even more far-fetched than vintage-specific bubbles.

Results We estimate a time-series for the organization-specific technological change. The series grows at about 1.75 percent per year but is more variable than the technology shocks extracted from productivity data or from information on the relative price of capital. Indeed, the series is nonmonotonic. This makes sense if patent-protection, technological secrecy and customer loyalty allow a generation of entrants to protect its products and techniques from being imitated by later entrants. Far from explaining why such imitation seems to be difficult, our model will simply assume that such imitation is impossible.

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that entered the NYSE anytime in the next two years and remained listed in 1998 as part of value brought into the market via a '20s merger. We also checked delisted '20s acquirers to determine if they were predecessors (through a later acquisition or sequence of acquisitions) to a CRSP firm that was listed in 1998, and treated these mergers similarly. The percentages obtained by dividing the 1998 value of all entering post-merger capital by the 1998 capital implied by the solid line in Figure 1 for each year of the 1920's were 6.81 in 1920, 0.53 in 1921, 0.67 in 1922, 1.77 in 1923, 0.02 in 1924, 1.91 in 1925, 7.32 in 1926, 2.07 in 1927, 5.95 in 1928, 0.41 in 1929, and 1.59 in 1930. Since the method attributes all entering capital to the merger targets even though much of it probably resided with the acquiring firm prior to merger and some may reflect post-merger appreciation of market value, these figures are likely to overstate the actual amounts of entering capital associated with mergers. This was necessary because we have no record of the value of unlisted targets prior to merger and entry of the acquirers.

The volatility of the estimated shock is not surprising considering that it is based on stock prices. Hayashi (1982, p. 223) and Pakes (1986, p. 403) have found that a rise in a firm's stock of capital or a rise in the number of its patents is accompanied by an increase in its stock-market value far larger than one would expect based on reasonable adjustment costs of capital and knowledge. Grossman and Shiller (1981) found that the S&P 500 index fluctuates more than the dividends of the firms that comprise it, and De Long and Shleifer (1991) found that closed-end fund values fluctuate more than the values of their component securities.

Our estimated cohort effects are stronger than one would find in other data. Previous work on vintage effects by Johnson (1980) on wages and by Levin and Stephan (1991) on research publications considers individuals (not firms) for whom one would expect negative age effects and positive vintage effects on performance. Since age and vintage are perfectly negatively correlated, if each variable operates linearly, their separate effects cannot be identified. To complicate things further, the passage of time matters too. Figure 1, however, uses data from a single date; it is the 1998 *cross-section* of stock-market shares arranged by vintage. This is where our 113-year series of technology estimates comes from, and so our estimates are free of any possibly "excess" volatility common to all firms. Indeed, Figure A1 shows that the differences in values of the various vintages are quite stable over time, which suggests that age per se does not matter here – the '20s firms are not especially valuable because they are 65 years old but because the pre-'20s vintages had much less value at a comparable age. We are not the first to have detected vintage effects in stock prices because Gerdes (1999) has already found them in the returns to buy-and-hold portfolios of stocks entering the CRSP.

2 Model

Our model follows a string of vintage capital models in the last few years, such as Atkeson and Kehoe (1997), Cooley *et al* (1999), Helpman and Trajtenberg (1998), Greenwood and Yorukoglu (1998), and Hornstein and Krusell (1996). As in Lucas's (1978) exchange economy, the representative agent, Crusoe, plants trees that bear fruit. He faces no uncertainty. The output of the final good is denoted by y_t, and Crusoe's consumption by c_t. Crusoe's lifetime utility is

$$\sum_{t=0}^{\infty} \beta^t U(c_t).$$

Trees. A tree's fruit-crop, y, depends on the tree's quality, θ, which is fixed over time, and on its variable input, m:

$$y = \theta^{1-\alpha} m^{\alpha}. \tag{1}$$

The variable input is produced using the services of capital, k, and labor, h:

$$m = k^{\eta} h^{1-\eta}$$

Since $\alpha < 1$, returns to the variable inputs diminish and Crusoe prefers to have many trees. A tree's quality has a vintage-specific part z and a tree-specific part ε:

$$\theta = z_v \varepsilon.$$

Crusoe starts every period with the same menu of tree-specific qualities given by the density of ε, $f(\varepsilon)$. Crusoe knows a tree's ε before he plants it, and therefore plants only qualities above some threshold. Once planted, the tree springs forth and yields fruit right away. The first few trees that Crusoe plants are of very high quality, and he will plant some at each date. Trees yield fruit in the same period and continue to yield that fruit for ever.

Variable inputs. Physical capital is homogeneous and it evolves as follows:

$$k_{t+1} = (1 - \delta) k_t + q_t x_t,$$

where x_t is fruit set aside for capital production. Labor quality, h, evolves exogenously, with a growth-factor γ. That is,

$$h_{t+1} = \gamma_h h_{t.}$$

Planting: We assume that ϕ_t is the fixed cost of planting a tree. If s_t is the worst tree planted at t, the number of trees planted is $n(s_t) \equiv \int_{s_t}^{\infty} f(\varepsilon) d\varepsilon$, and in units of fruit the cost is $\phi_t n(s_t)$.

Income identity: Aggregate output, Y_t, is divided between consumption, investment in physical capital, and investment in trees:

$$Y_t = c_t + x_t + \phi_t n(s_t).$$

2.0.1 Interpretation

The model contains four sources of technological change:

1. *In trees*: z_t is the quality of the technology embodied in trees planted at date t. We refer to z as organization capital.

2. *In equipment*: q_t is a technology parameter embodied in the equipment made at date t.

3. *In finance*: ϕ_t is the cost of planting trees, the cost of starting a project. One part of this cost is presumably the cost of getting funds.

4. In *labor quality*: h_t is a labor-augmenting technological change parameter.

To get something that we can work with, we have sacrificed much realism. First, technology is exogenous and perfectly foreseen. Second, trees do not need maintenance and so, as in Solow (1960), they are never abandoned, regardless of their quality. Third, obsolescence of trees occurs only through interest-rate changes, an assumption that Hobijn and Jovanovic (forthcoming) relax. Fourth, tree-quality is known before the tree is planted, an assumption that Jovanovic (1982) relaxes.

2.0.2 Crusoe's decision problem

Each period, Crusoe spreads his capital among trees so as to maximize total output

$$Y_t = \max_{k_v(\varepsilon)} \left\{ \sum_{v=-\infty}^{t-1} \int_{s_v}^{\infty} (z_v \varepsilon)^{1-\alpha} \left[k_v^{\eta}(\varepsilon)\, h_v^{1-\eta}(\varepsilon) \right]^{\alpha} f(\varepsilon)\, d\varepsilon \right\},$$

subject to his two resource constraints

$$\sum_{v=-\infty}^{t-1} \int_{s_v}^{\infty} k_v(\varepsilon) f(\varepsilon)\, d\varepsilon \le k_t, \qquad \text{and} \qquad \sum_{v=-\infty}^{t-1} \int_{s_v}^{\infty} h_v(\varepsilon) f(\varepsilon)\, d\varepsilon \le h_t.$$

The following aggregation property will be quite useful:

Proposition 1

$$Y_t = A_t^{1-\alpha} \left(k_t^{\eta} h_t^{1-\eta} \right)^{\alpha}$$

where

$$A_t = \sum_{v=-\infty}^{t-1} z_v H(s_v) \tag{2}$$

Proof: Take any distribution on the line, say $\Psi(\theta)$. The optimal policy to the problem

$$\max_{k(\theta),h(\theta)} \left\{ Y = \int \theta^{1-\alpha} \left[k^{\eta}(\theta)\, h(\theta)^{1-\eta} \right]^{\alpha} d\Psi(\theta) \right\} \ s.t. \int k(\theta)\, d\Psi(\theta) = k \text{ and } \int h(\theta)\, d\Psi(\theta) = h$$

is of the form $k(\theta) = k\theta/\bar{\theta}$ and $h(\theta) = h\theta/\bar{\theta}$, where $\bar{\theta} = \int \theta d\Psi(\theta)$. Substituting for $k(\theta)$ and $h(\theta)$ into the criterion, $Y = \left(\bar{\theta}\right)^{1-\alpha} \left(k^{\eta} h^{1-\eta}\right)^{\alpha}$. Finally, letting $\Psi(\theta)$ denote the distribution of quality among all living vintages of trees, we get $\bar{\theta} = A_t$. ■

Then

$$\begin{aligned} c_t &= A_t^{1-\alpha} m_t^{\alpha} - x_t - \phi_t n(s_t) \\ &= A_t^{1-\alpha} m_t^{\alpha} - \frac{(k_{t+1} - (1-\delta) k_t)}{q_t} - \phi_t n(s_t), \end{aligned}$$

and, from (2), the law of motion for A_t is

$$A_{t+1} = A_t + z_t H(s_t) \tag{3}$$

which we can solve for s and write the result as

$$s = \xi(z, A, A'),$$

so that $\frac{\partial \xi}{\partial A'} = -\frac{1}{zsf(s)}$ and $\frac{\partial \xi}{\partial A} = \frac{1}{zsf(s)}$. The Bellman equation pertaining to Crusoe's decision problem is

$$V_t(k, A) = \max_{k', A'} \left\{ \begin{array}{c} U\left(A^{1-\alpha}\left(k^{\eta} h_t^{1-\eta}\right)^{\alpha} - \frac{k' - (1-\delta)k}{q_t} - \phi_t \left[1 - F\left\{\left[\xi\left(z_t, A, A'\right)\right]\right\}\right]\right) \\ +\beta V_{t+1}(k', A') \end{array} \right\}.$$

This problem is now unconstrained. Its two first-order conditions are

$$-\frac{1}{q_t} U'(c_t) + \beta \frac{\partial V_{t+1}}{\partial k_{t+1}} = 0,$$

and,

$$-\frac{\phi_t}{z_t s_t} U'(c_t) + \beta \frac{\partial V_{t+1}}{\partial A_{t+1}} = 0.$$

The envelope theorem gives us

$$\frac{\partial V_t}{\partial k} = \left(\alpha \eta \frac{y_t}{k_t} + \frac{(1-\delta)}{q_t}\right) U'(c_t)$$

and

$$\frac{\partial V_t}{\partial A} = \left((1-\alpha)\frac{y_t}{A_t} + \frac{\phi_t}{z_t s_t}\right) U'(c_t).$$

Updating these two expressions to $t+1$ and substituting into the previous two gives us the two first order conditions purged of the unknown function V:

$$-\frac{1}{q_t} U'(c_t) + \beta\left(\alpha \eta \frac{y_{t+1}}{k_{t+1}} + \frac{1-\delta}{q_{t+1}}\right) U'(c_{t+1}), \tag{4}$$

and

$$-\frac{\phi_t}{z_t s_t} U'(c_t) + \beta\left((1-\alpha)\frac{y_{t+1}}{A_{t+1}} + \frac{\phi_{t+1}}{z_{t+1} s_{t+1}}\right) U'(c_{t+1}) = 0. \tag{5}$$

2.0.3 Decentralizing the allocation

Markets are competitive and there are no external effects, and so the optimum decentralizes. Defining the rate of interest r_t implicitly by $\frac{1}{1+r_t} = \frac{\beta U'(c_{t+1})}{U'(c_t)}$, we combine (4) and (5) into one condition:

$$1 + r_t = q_t\left(\alpha \eta \frac{y_{t+1}}{k_{t+1}} + \frac{(1-\delta)}{q_{t+1}}\right) = \frac{z_t s_t}{\phi_t}\left((1-\alpha)\frac{y_t}{A_t} + \frac{\phi_{t+1}}{z_{t+1} s_{t+1}}\right)$$

This asset market condition equates the returns to three different forms of saving and storage: (1) earn $1 + r_t$ dollars per dollar saved in the bank; (2) convert the dollar into q_t machines, use them to produce (i.e., receive a rental of) $q_t \alpha \eta y_{t+1}/k_{t+1}$ units of tomorrow's output, and sell the undepreciated machines at $1/q_{t+1}$ dollars per machine; and (3) convert the dollar into $1/\phi_t$ trees of quality $z_t s_t$ each, get their dividends tomorrow and then sell them. Trees draw the residual income and their share of output is $(1-\alpha)$. The quantity $(1-\alpha)\left(\frac{k_{t+1}^{\eta}}{A_{t+1}}\right)^{\alpha} h_{t+1}^{(1-\eta)\alpha}$ is the additional dividend, and the quantity $\frac{\phi_{t+1}}{z_{t+1}s_{t+1}}$ is the resources that Crusoe can save tomorrow by having the additional surviving trees. So, the last (or worst) tree that is planted in each period has the same yield as the purchase of a machine. In other words, the cost of planting the marginal tree equals the discounted sum of the (marginal utility of) consumption that is provides. The discounted output of the inframarginal trees exceeds the cost of planting them. Good vintage years (i.e., high z years) will see more of the low-quality trees being planted which means that mean vintage-quality should be positively related to its within-vintage variance.[6]

Next, the factor market. A firm equates the marginal product of capital to its user cost J_t. That is,

$$\begin{aligned} \frac{q_t \alpha \eta y_{t+1}}{k_{t+1}} &= 1 + r_t - \frac{q_t(1-\delta)}{q_{t+1}} \equiv J_t \\ &\approx r_t + \delta + g_{q,t} \end{aligned} \tag{6}$$

where $g_{q,t}$ is the growth of q_t at date t. In units of the final good, the price of capital is $1/q_t$ and the user cost of an efficiency unit of capital is J_t/q_t.

Similarly, while Crusoe takes his labor endowment as exogenous, for a firm it is a choice variable. The firm will set the marginal product of skill equal to its shadow price:

$$\alpha(1-\eta)\frac{y_t}{h_t} \equiv w_t$$

When the inputs of k and h are priced in this way, the net income from a tree is

$$\max_{k,h}\left\{\theta^{1-\alpha} m^{\alpha} - Jk - wh\right\} = (1-\alpha)\, y(\theta, w, J),$$

where

$$y(\theta, w, J) = \Omega(w, J)\,\theta$$

is the tree's fruit yield and where

$$\Omega(w, J) \equiv \left(\frac{\alpha \eta^{\eta}(1-\eta)^{1-\eta}}{w^{1-\eta} J^{\eta}}\right)^{\alpha/(1-\alpha)}.$$

[6] Fernando Alvarez pointed this property out to us, and it is strongly confirmed by the data – see Figure 6.

The price of a tree is the discounted present value of the income it generates:

$$p_t(\theta) = \pi_t \theta,$$

where

$$\pi_t = (1-\alpha)\sum_{j=0}^{\infty} \beta^j \frac{U'(c_{t+j})}{U'(c_t)} \Omega(w_{t+j}, J_{t+j}). \tag{7}$$

Let $P_{t,v}$ be the date - t value of all vintage - v trees:

$$P_{t,v} = \pi_t z_v \int_{s_v}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon \tag{8}$$

It depends positively on the tree-vintage shock z_v, positively on vintage v investment as indexed by the identity of the marginal project s_v, negatively on the *growth* of q_t because that raises J_t, and negatively on the price of skill w_t.

We can now predict the series for the solid line in Figure 1. Since y is linear in θ, so is p. That is, $p_t(\theta) = \pi_t \theta$, where π_t does not depend on the tree's vintage. At any date, then, the value of the capital of various vintages is proportional to the aggregate quality that each vintage accounts for. Thus we get a series for the percentage of 1998 value of each vintage that we had earlier plotted as the solid line in Figure 1. According to the model, that series is

$$\frac{P_{t,v}}{\sum_{v' \le t} P_{t,v'}} = \frac{z_v \int_{s_v}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon}{\sum_{v' \le t} z_{v'} \int_{s_{v'}}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon},$$

where $t = 1998$. Now let $\lambda > 1$, and let ε have the Pareto distribution

$$f(\varepsilon) = \varepsilon^{-(1+\lambda)}, \tag{9}$$

for $\varepsilon > 0$. Then $\int_{s_v}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon = \int_{s_v}^{\infty} \varepsilon^{-\lambda} d\varepsilon = \frac{1}{\lambda - 1} s_t^{1-\lambda}$,and so

$$\frac{P_{t,v}}{\sum_{v' \le t} P_{t,v'}} = \frac{z_v s_v^{1-\lambda}}{\sum_{v' \le t} z_{v'} s_{v'}^{1-\lambda}}.$$

This is the parametrized-model's formula for the solid line in Figure 1. Note that is does not contain π_t.

2.0.4 Long run growth

Assume that $\gamma_h \ge 1$, $\gamma_q \ge 1, \gamma_z \ge 1$ and $\gamma_\phi \le 1$ are given. By "γ_b", we mean the growth factor of variable "b". We shall describe a path along which c grows at the growth factor γ. The following result is proved in the appendix:

Proposition 2 *The long-run growth factor for Y is*

$$\gamma = \left(\left[\gamma_z \gamma_\phi^{(1-\lambda)/\lambda} \right]^{1-\alpha} \gamma_q^{\eta\alpha} \gamma_h^{(1-\eta)\alpha} \right)^{\lambda/[\lambda\alpha(1-\eta)+1-\alpha]}$$

and its long run growth-rate, approximately, is

$$g \approx \frac{\lambda}{\lambda\alpha(1-\eta)+1-\alpha} \left\{ (1-\alpha) g_z + \eta\alpha g_q + \alpha(1-\eta) g_h + \frac{(1-\alpha)(1-\lambda)}{\lambda} g_\phi \right\}.$$

If $\eta = 1$ and the labor input drops out, these expressions simplify to

$$\gamma = \gamma_q^{\lambda\alpha/(1-\alpha)} \gamma_z^{\lambda} \gamma_\phi^{1-\lambda}$$

or, in terms of growth rates, the long run growth rate of Y is

$$g \approx \frac{\lambda\alpha}{1-\alpha} g_q + \lambda g_z + (1-\lambda) g_\phi.$$

A comment on the heterogeneity of trees and the effect on growth of the rollback of the extensive margin. If the planting of trees becomes cheaper over time, $\gamma_\phi < 1$ and $g_\phi < 0$. If ϕ declines, the parameter λ determines how much that decline will raise growth, and we shall elaborate on how it works.

The number of trees planted is $n(s) = \int_s^\infty \varepsilon^{-(1+\lambda)} d\varepsilon = \frac{1}{\lambda} s^{-\lambda}$, and their aggregate quality is $H(s) \equiv \int_s^\infty \varepsilon^{-\lambda} d\varepsilon = \frac{s^{1-\lambda}}{\lambda-1}$. As $s \to 0$, $n(s)$ and $H(s)$ both grow without bound, but quality per tree, $\frac{H(s)}{n(s)} = \left(\frac{\lambda}{\lambda-1}\right) s$, converges to zero as $s \to 0$. As Figure 2 shows, the higher is λ, the more slowly does quality converge to zero, and this opens the door to a bigger boost to growth as the extensive margin rolls down to zero.

3 Estimation

To relate the model to the data, we assume that a firm owns and manages exactly one tree, so that each tree planted at date t represents an initial public offering of a new firm. Thus we shall explain the pattern in Figure 1 with the z's – that is, with vintage organization capital shocks. In reality, firms can and often do produce output without listing on the stock market, and we shall adjust for that fact, among others.

3.1 Estimating the z's from the series in Figure (1).

Now let $p_{t,v}^{\min}$ denote the period-t price of the lowest-quality (i.e., $\theta = z_v s_v$) tree planted at date v. Then,

$$p_{t,v}^{\min} = \pi_t z_v s_v, \qquad \text{or} \qquad s_v = \frac{p_{t,v}^{\min}}{\pi_t z_v}. \tag{10}$$

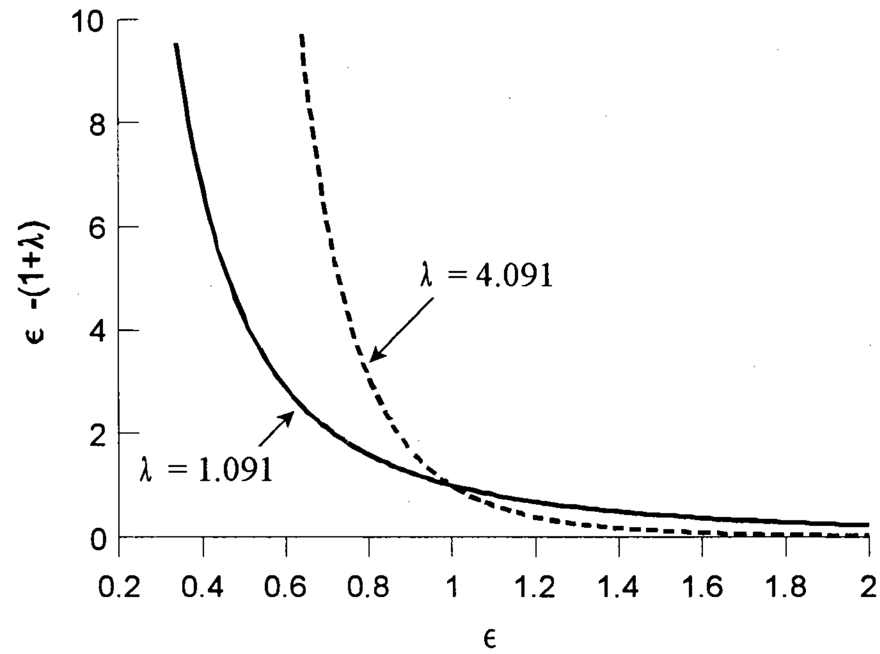

Figure 2: The Pareto Distribution.

Substituting, $(\pi_t)^{-(1-\lambda)}$ cancels, and

$$\frac{P_{t,v}}{\sum_{v'<=t} P_{t,v'}} = \frac{z_v^\lambda \left(p_{t,v}^{\min}\right)^{1-\lambda}}{\sum_{v'<=t} z_{v'}^\lambda \left(p_{t,v'}^{\min}\right)^{1-\lambda}}.$$

For fixed t, this is a set of implicit functions in the z_v's with the appealing feature that π_t and the variables that influence it such as w, J, and taxes do not enter. Estimates of the z's based on this equation are, in this sense, robust.

2.0.5 Correcting for the trend toward equity

We do need to correct these equations for the trend away from debt and into equity. Letting e_t denote total stock-market capitalization and d_t debt outstanding, we assume that new firms raise their capital through debt and equity in the same proportion as the old capital outstanding. Therefore, a fraction

$$\xi_t \equiv \frac{e_t}{e_t + d_t}$$

of capital formation at date is financed through stocks. Figure 4 presents our estimates ξ.[7] We do not explain the rise in the series, but we try to account for it by

[7] We define U.S. business debt as the market value of corporate bonds and commercial and industrial bank loans For 1945-98, book values are from the *Flow of Funds* (Table L.4 lines 5 and

Figure 3: Estimates of ξ.

interpreting the solid line in Figure 1 to be the ratio

$$\frac{\xi_v P_{98,v}}{\sum_{v' \leq 98} \xi_{v'} P_{98,v'}} = \frac{\xi_v z_v^\lambda \left(p_{98,v}^{\min}\right)^{1-\lambda}}{\sum_{v' \leq 98} \xi_{v'} z_{v'}^\lambda \left(p_{98,v'}^{\min}\right)^{1-\lambda}}.$$

6). For 1885-1944, the book value of outstanding corporate bonds is from W. Braddock Hickman (1952), and that of bank loans is from *All Bank Statistics* and the *Historical Statistics of the United States*. Since the last two sources report June 30 figures, we average across years for consistency with the calendar-year basis of the *Flow of Funds*. After ratio-splicing these components into a continuous series, we convert to market values using the average annual yields on Moody's AAA-rated corporate bonds for 1919-98 and Hickman's "high grade" bond yields, which line up precisely with Moody's, for 1900-18. We use yields on "high-grade industrial bonds" from Milton Friedman and Anna J. Schwartz (1982) for 1885-99. To determine market value, we let r_t be the bond interest rate and compute the weighted average

$$r_t^* = \frac{1}{\sum_{i=1885}^{t} (1-\delta)^{t-i}} \sum_{i=1885}^{t} (1-\delta)^{t-i} r_{t-i}.$$

We choose $\delta = 10\%$ to approximate the growth of new debt plus retirements of old debt, and multiply the book value of outstanding debt by the ratio $\frac{r_t^*}{r_t}$ to obtain its market value.

This lets us solve for the sequence $\varphi_v = \frac{\xi_v z_v^\lambda \left(p_{98,v}^{\min}\right)^{1-\lambda}}{\sum_{v' \leq 1998} \xi_{v'} z_{v'}^\lambda \left(p_{98,v'}^{\min}\right)^{1-\lambda}}$. Since we know ξ_v and $p_{t,v}^{\min}$, once we have an estimate λ, we can calculate our estimates of the z's, call them $\hat{z}$'s.

3.1.2 Estimating λ

The number of trees planted at date t is given by $n(s) = \int_s^\infty \varepsilon^{-(1+\lambda)} d\varepsilon = \frac{1}{\lambda} s^{-\lambda}$. The value of the marginal tree is

$$p_{t,t}^{\min} = z_t \pi_t s_t,$$

while, if $\lambda > 1$, the total value of all trees planted at t is

$$P_{t,t} = z_t \pi_t \int_{s_t}^\infty \varepsilon^{-\lambda} d\varepsilon = \frac{1}{\lambda - 1} z_t \pi_t s_t^{1-\lambda}.$$

Then

$$\frac{n_t p_{t,t}^{\min}}{P_{t,t}} = \frac{\lambda - 1}{\lambda} = \frac{p_{t,t}^{\min}}{P_{t,t}/n_t} = \frac{\text{smallest IPO}}{\text{average IPO}} \equiv \omega_t < 1.$$

Therefore, $\lambda = \frac{1}{1-\omega_t}$. Our estimate for λ use all the years together as follows:

$$\hat{\lambda} = \frac{1}{113} \sum_{t=1886}^{1998} \frac{1}{1 - \omega_t}.$$

Note that this estimator does not involve (π_t).

3.1.3 From $\hat{\lambda}$ to the $\hat{z}$'s

Having found $\hat{\lambda}$, we compute the series for the $\hat{z}$'s shown in Figure 4. Since not all of the early years have surviving firms, we denote interpolated values by a dashed line. An OLS regression of the logarithm of the $\hat{z}$'s on a linear time trend implies an average growth rate of 1.75 percent per year. Gort, Greenwood and Rupert (1999, Figure 2) find that the vintage effects in the rent on structures are similar to our estimates of the shocks – a U-shaped pattern – but their estimates are not "cleansed" of quality in the way that we have tried to cleanse ours using $p_{\min}$.

4 Vintage organization capital

The $\hat{z}_v$'s are our estimates of cohorts' organization capital. What does it mean to say that the '20s cohort has more organization capital than the '50s cohort? Why would firms ability to organize get worse in that way? Organization capital is whatever makes a group of people and assets more productive together than apart. Firm-specific human (Becker 1962), management (Prescott and Visscher 1980), and physical (Ramey and Shapiro 1996) capital, and a cooperative disposition in the firm's

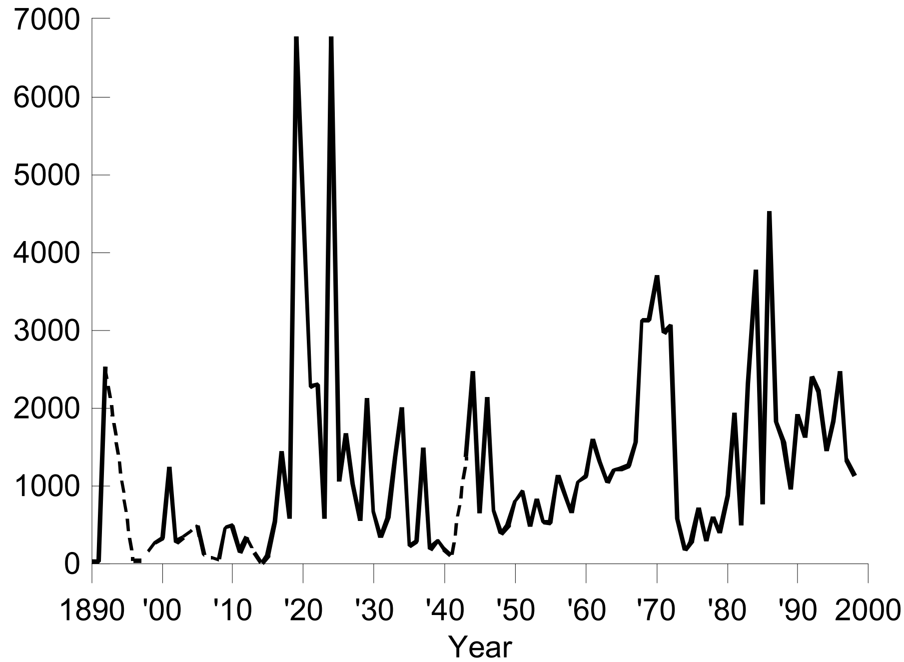

Figure 4: Estimates of z.

workforce (Eeckhout 2000 and Rob and Zemsky 1997) are examples of organization capital. Most of that capital is probably not on the firm's books and is an "intangible" asset.

Now, not all organization capital is intangible, nor is all intangible capital a form of organization capital. For example, prior to 2000, general-purpose software was expensed and, being highly durable, it would be a form of intangible capital but not a part of organization capital – in our model it would be part of k and not part of z. Conversely, any physical capital that is partly specific to the firm's product is a form of tangible capital, a fraction of which is organization capital. Organization capital differs from other capital – tangible or intangible – because it is worth more to the firm than it is to other firms. An example is a patent on a technological invention. To get the most out of its patent, a firm will buy specific machinery and hire the kind of labor needed to work that technology. The organization is then built around the idea, and it determines the value of the firm. The idea, the labor, and the capital, have all been chosen to fit one another, and any component taken on its own is worth less elsewhere.

Being costly to adjust, an organization's capital will reflect conditions that prevailed when the organization was created. The firm founder's idea, the patents that he may take out on it, and the plant and equipment that he acquires at the IPO stage will, presumably, all reflect technology that was state of the art and the relative

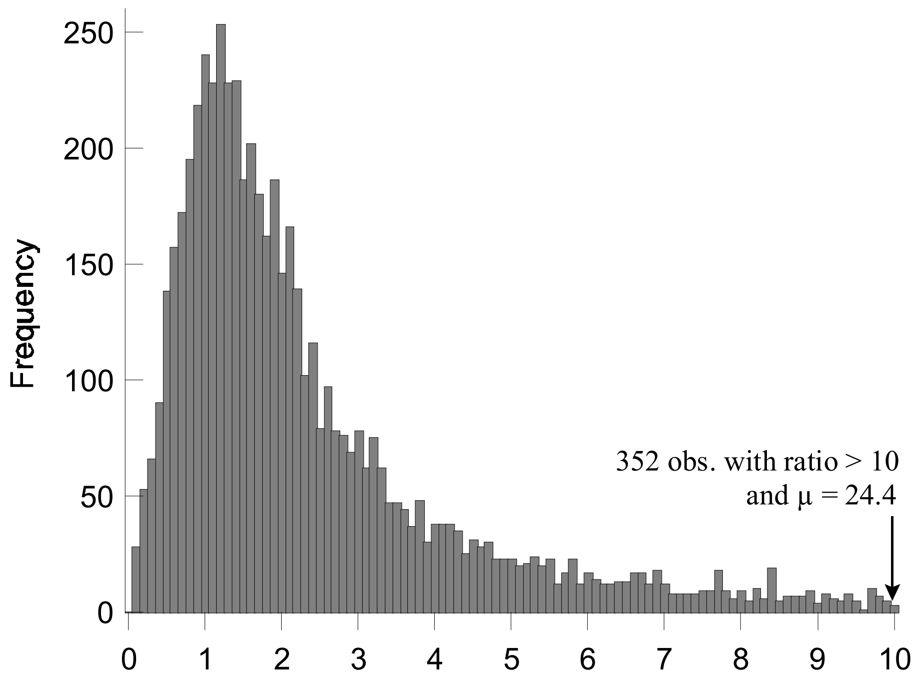

Figure 5: Market-to-book ratios for 1998 CRSP/Compustat firms.

prices of inputs that prevailed then. The firm's founder and its original managers will often pick their successors and the initial character of the organization may live on even after they are no longer with the firm. The firm will, in other words, carry an "imprint", as Carroll and Hannan (2000, ch. 9) put it, and, if the organization capital is subject to adjustment costs, the imprint will persist. Organization capital must indeed be costly to change, because many a firm will disband, sell its assets off at a mere fraction of their marginal internal value and impose on its members the costs of searching for new jobs, rather than reorganize internally.

To sum up: A cohort can partially appropriate the new technologies and products of its day, thereby leaving less rents for incumbents and for succeeding cohorts. The precise mechanism by which this happens is not yet clear to us, but this is what the data seem to be saying, and what our model simply assumes.

4.0.4 Estimating α

One estimate of α is the private returns to scale of the reproducible factors k and h. Organization capital is not reproducible here. Now, α must be less than one if we are to have a range of efficiencies in equilibrium. We could take an estimate from the literature (which would put α at around 0.9 or 0.95), but it is more instructive to derive it from the observed market-to-book (M/B) values of firms since this source of information on α has not yet been used.

Figure 5 is the frequency distribution of M/B for all 6,051 firms listed in the combined CRSP and Compustat files in 1998 that include a book value suitable for computation. Market values represent common equity only, while book values correspond to the firm's residual claim.[8] In the model, all firms have the same M/B if q is constant and if ϕ is not on the books (e.g., underwriters' and lawyers' fees). Let us derive M/B in this special case. From (6) one finds that in consumption units the capital inside a firm k would be proportional to y as follows:

$$\frac{k_t}{q} = \frac{\alpha \eta y_t}{r_t + \delta} \equiv B.$$

This is the firm's book value If r_t were constant at r, the market value of such a firm would be $M \equiv (1 - \alpha)\, y/r$. Therefore, for all firms

$$\frac{M}{B} = \frac{(1 - \alpha)\,(r + \delta)}{r \alpha \eta}.$$

The 1998 median of the M/B distribution in Figure 5 is 1.79. If $\eta = 0.33$, $r = 0.055$, and $\delta = 0.125$, we should have

$$\frac{(1 - \alpha)\,(r + \delta)}{r \alpha \eta} = 1.79, \text{ so that } \frac{\alpha}{1 - \alpha} = \frac{(0.18)}{(1.79)\,(0.33)\,(0.055)},$$

which gives $\alpha = 0.85$.

Now, as Figure 5 shows, M/B is not the same for all firms. It turns out that M/B varies widely both within and across vintages. Moreover, it does so in a way consistent with ϕ being partly on the books. Optimal planting implies (see (5)) that when z is high, s is low. That is, the better the vintage, the more low-quality trees are planted, and this raises the dispersion of qualities in that vintage. Now, when ϕ is on the books, this translates into a rise in both the mean and variability of M/B within a vintage, and this is exactly what happens. The solid line in Figure 6 presents the average M/B and its standard deviations by entry year for a large subsample of firms in our extended CRSP database.[9] Dispersion in the market-to-book values is highly correlated with their level ($\rho = .90$).

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[8]The residual book claim is the sum of common shares valued at par and any premia on stock, surplus, retained earnings, and net undivided profits that might appear on the firm's consolidated balance sheet. We omitted firms with negative values for net common equity from the plot since they imply negative market to book ratios. We also excluded firms with market to book ratios that exceeded 100, since our "residual" definition of book equity could at times be negligible even though the firm's total liabilities were quite large.

[9]The ratios depicted in Figure 6 are annual averages. We collect the balance sheet quantities in 1998, 1989, 1980, 1955, and 1928, all business cycle peaks, and use the market-to-book ratio in the latest year for firms with multiple observations. To excise time effects, we multiply non-1998 observations by the ratio of the average M/B of all firms (not just entrants or latest observations) in 1998 to that in the appropriate sampling year. The M/B's were 1.79 in 1928 (227 obs.), 1.58 in 1955

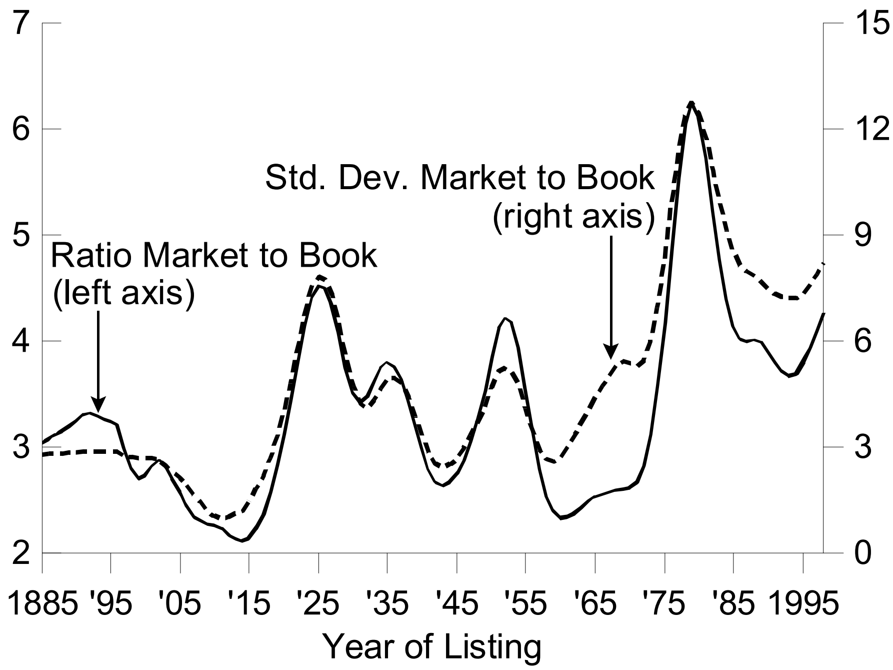

Figure 6: Market to book ratios and their variation for listed firms by entry year.

5 Entry distributions

Let $N_t(p)$ denote the number of firms that IPO at a value exceeding p. Since $p_t(\theta) = \pi_t\theta = \pi_t z_t \varepsilon$, and since $f(\varepsilon) = \varepsilon^{-(1+\lambda)}$,

$$N_t(p) = \int_{p/\pi_t z_t}^{\infty} f(\varepsilon)\, d\varepsilon = \frac{1}{\lambda}\pi_t^{\lambda} z_t^{\lambda} p^{-\lambda}$$

for $p \geq p_{t,t}^{\min}$, and zero for $p < p_{t,t}^{\min}$. The total number of entrants is $N_t\left(p_t^{\min}\right)$. The density is

(256 obs.), 3.21 in 1980 (4,769 obs.), 3.63 in 1989 (5.952 obs.), and 3.58 in 1998 (6,051 obs.). Book values from 1998, 1989 and 1980 are from Compustat (data item #60), while those from 1955 and 1928 are from *Moody's Industrial Manual* and *Moody's Railroad Manual*. Of the 10,658 observations included in Figure 6, 6,051 are from 1998, 2,457 from 1989, 1,769 from 1980, 156 from 1955, and 225 from 1928. Overall, this represents nearly half of the firms in our extended CRSP database.

Figure 6 is not quite the same as Figure 2 of Jovanovic and Rousseau (2001) who define the market-book ratio differently, using total balance sheet liabilities as the book value of the firm, and obtaining market value by subtracting out common equity at par and adding it back in at market value. This is equivalent to adding debt and current liabilities to both numerator and denominator of the ratios, thereby making them smaller and less variable than those presented here. That paper tests an entirely different model. Since our present model focuses on common equity, we consider the current measure more appropriate here. Figure 6 is based on a sample that is larger by 4,164 observations.

$$-\frac{dN_t}{dp} = \pi_t^\lambda z_t^\lambda p^{-(1+\lambda)} \equiv n_t(p).$$

Total value created by date-t entrants is

$$\begin{aligned}
\hat{V}_t &= \pi_t z_t \int_{p^{\min}/\pi_t z_t}^{\infty} \varepsilon f(\varepsilon)\, d\varepsilon = \pi_t z_t \int_{p^{\min}/\pi_t z_t}^{\infty} \varepsilon^{-\lambda} d\varepsilon = \pi_t z_t \, \frac{1}{1-\lambda} \varepsilon^{1-\lambda} \Big|_{p^{\min}/\pi_t z_t}^{\infty} \\
&= \frac{1}{\lambda - 1} \pi_t^\lambda z_t^\lambda p^{1-\lambda} = \frac{\lambda p_t^{\min}}{\lambda - 1} N_t\left(p_t^{\min}\right).
\end{aligned}$$

Note that $p^{-(1+\lambda)} = \exp\left\{\ln\left[p^{-(1+\lambda)}\right]\right\} = \exp\{-(1+\lambda)\ln p\}$. Substituting this into the previous equation and correcting for the share of equity in external finance and the average corporate income tax rate (τ) for each year, we obtain the density of n_t[10]

$$n_t(p) = \begin{cases} \xi_t(1-\tau)\pi_t^\lambda z_t^\lambda \exp\{-(1+\lambda)x\} & \text{for } x \geq \ln p_t^{\min}, \\ 0 & \text{for } x < \ln p_t^{\min} \end{cases}.$$

We have already estimated λ and the z_t sequence, and we shall use the average size of the smallest one-third of entrants in a given year from the data as a robust estimate of $p_t^{\min}$. Figure 7 presents the series.[11] Finally we need the model's prediction for π_t in (7). To compute this, we shall assume that $U(c) = \ln c$ and use the actual sequence for per capita real consumption.[12] For w we would want the time-wage (wh) divided by h, but we do not have a reliable measure of h, and so hold w constant at 1 throughout.

As for J, we will use the growth rate of relative equipment prices, after correcting for changes in quality, to estimate the technology parameter q. Krusell et al. (2000) build such a series from 1963 using the consumer price index to deflate the quality-adjusted estimates of producer equipment prices from Gordon (1990, table 12.4, col. 2, p. 541). Since Gordon's series ends in 1983, they use VAR forecasts to extend it through 1992. We start with Krusell *et al.* and work backward, deflating Gordon's remaining estimates (1947-62) with an index for non-durable consumption goods prices that we derive from the National Income Accounts. Since we are not aware of

[10]The average corporate tax rates for 1953-85 are from Auerbach (1983) and are continued through 1998 as the ratio of income taxes before credits to taxable income from various issues of the *Statistical Abstract of the United States*. We use the ratio of income taxes to net income from *Historical Statistics* (series Y-389 divided by series Y-388) for 1909-52, which marks the inception of the corporate income tax. A ratio splice in 1953 adjusts for differences between net and taxable incomes that make the denominators of the tax rate measures not directly comparable across data sources.

[11]The average firm size and average number of employees per business concern are also included in Figure 7. These series indicate that the decline in entry size after 1960 was not simply the result of a tendency for businesses to downsize.

[12]We construct the consumption series from unpublished tables underlying Kuznets (1961) for 1885-1928 and the NIPA for 1929-1998.

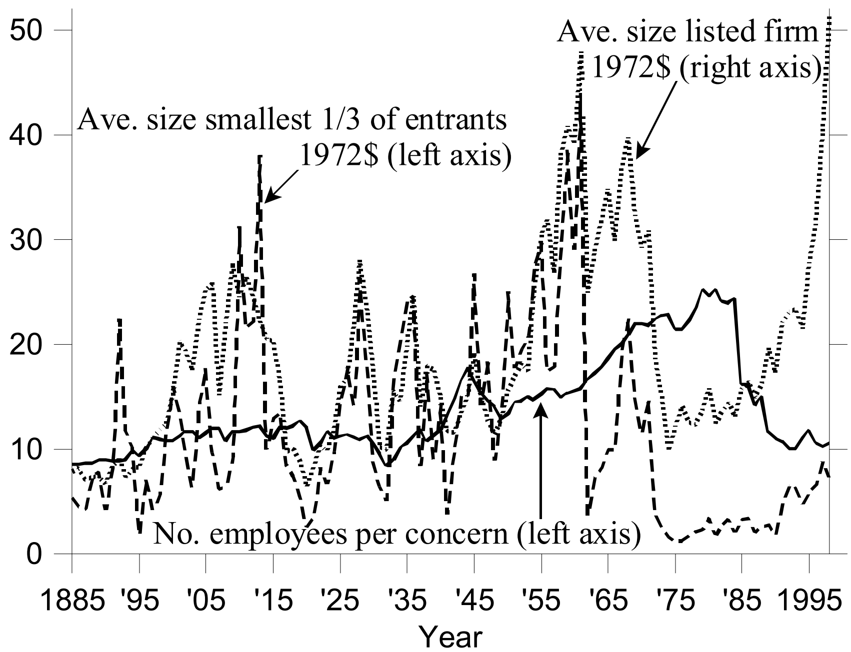

Figure 7: Characterizations of firm size.

a quality-adjusted series for equipment prices prior to 1947, we use the average price of electricity as a proxy for 1902-46, and an average of Brady's (1966) deflators for the main classes of equipment for 1885-1902.[13] We deflate the pre-1947 composite using the Bureau of Labor Statistics (BLS) consumer prices index of all items (*Historical Statistics*, series E135) for 1913-46 and the Burgess cost of living index (*Historical Statistics*, series E184), which has greater precision than the BLS series, for 1885-1912. Figure 8 presents the resulting equipment price series.

With the model calibrated, we pool the data in each decade, calculate the number and value of entering firms, and then compare $N_t\left(p_t^{\min}\right)$ and $\hat{V}_t$ to the observed quantities by decade.[14] To do this, we set the sum of the predicted decadal values

[13]Electricity prices from 1926-46 are the average of all electric services in cents per kilowatt-hour from *Historical Statistics* series S119. We use prices for all consumption uses of electicity for 1902-26, and interpolate under a constant growth assumption between five-year benchmarks from 1902 through 1917. The equipment price deflators that we average in 1879, 1889 and 1900 (Brady, 1966, table 2b, p. 111) include industrial machinery, farm equipment, office and store equipment, railroad equipment, ships and boats, conveyances, professional and scientific equipment, and carpentry and mechanics tools. We again interpolate using constant growth rates between these benchmarks, and to avoid smoothing bias use a similarly interpolated version of the consumer price index over this period.

[14]We should note, however, that the predicted entry values are conditional on the realized $p_t^{\min}$ sequence that we cannot predict because we have no measure of ϕ_t so that we treat the latter as a residual.

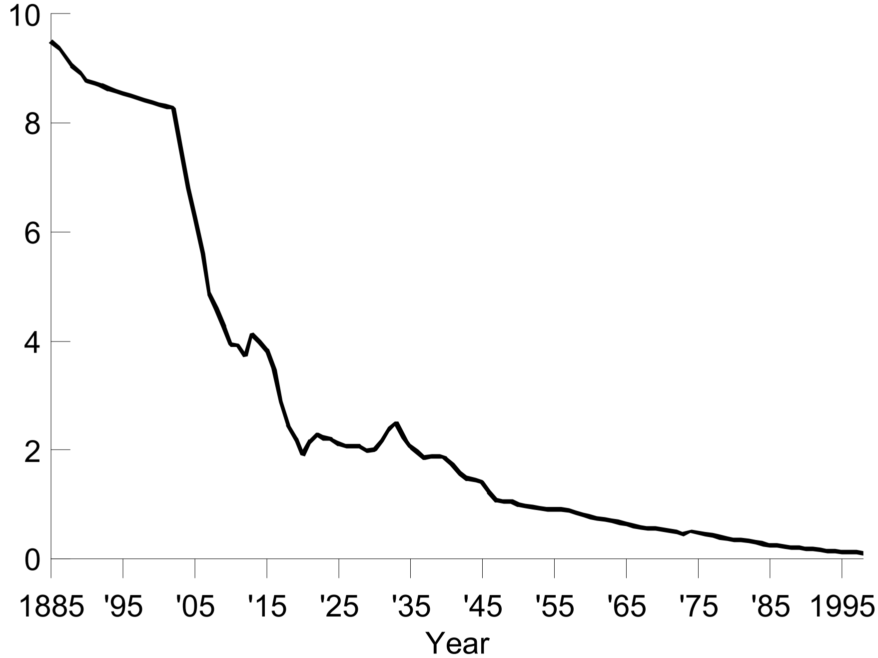

Figure 8: The relative price of equipment

equal to observed totals. As is clear from the results reported in Table 1, the model generally overpredicts the amount of new capital that enters the market before 1940 and, with the exception of the 1980s, underpredicts in more recent decades. There are several factors which contribute to the lack of fit. First, and most importantly,

Table 1: Goodness of Fit

	Number of Firms			Value Entrants (bil. 1998$)		
	Model	Data	%	Model	Data	%
1890-99	1748	550	+217.7	508.7	152.5	+233.6
1900-09	346	540	-35.8	301.4	175.5	+71.9
1910-19	1885	1040	+81.3	928.4	301.5	+207.9
1920-29	8142	2715	+199.9	2954.5	1007.1	+193.3
1930-39	774	1140	-32.1	592.4	342.9	+72.8
1940-49	461	1355	-66.0	475.6	3436.1	-86.2
1950-59	133	1270	-89.5	232.3	599.4	-61.2
1960-69	2177	10040	-78.3	1362.6	3056.3	-55.4
1970-79	14727	22585	-34.8	2951.6	3820.7	-22.7
1980-89	51864	31610	+64.1	10554.2	4695.8	+124.8
1990-99	25237	34650	-27.2	7754.4	11028.2	-29.7

the estimated z's are based on firms that survive until 1998. Since our model predicts

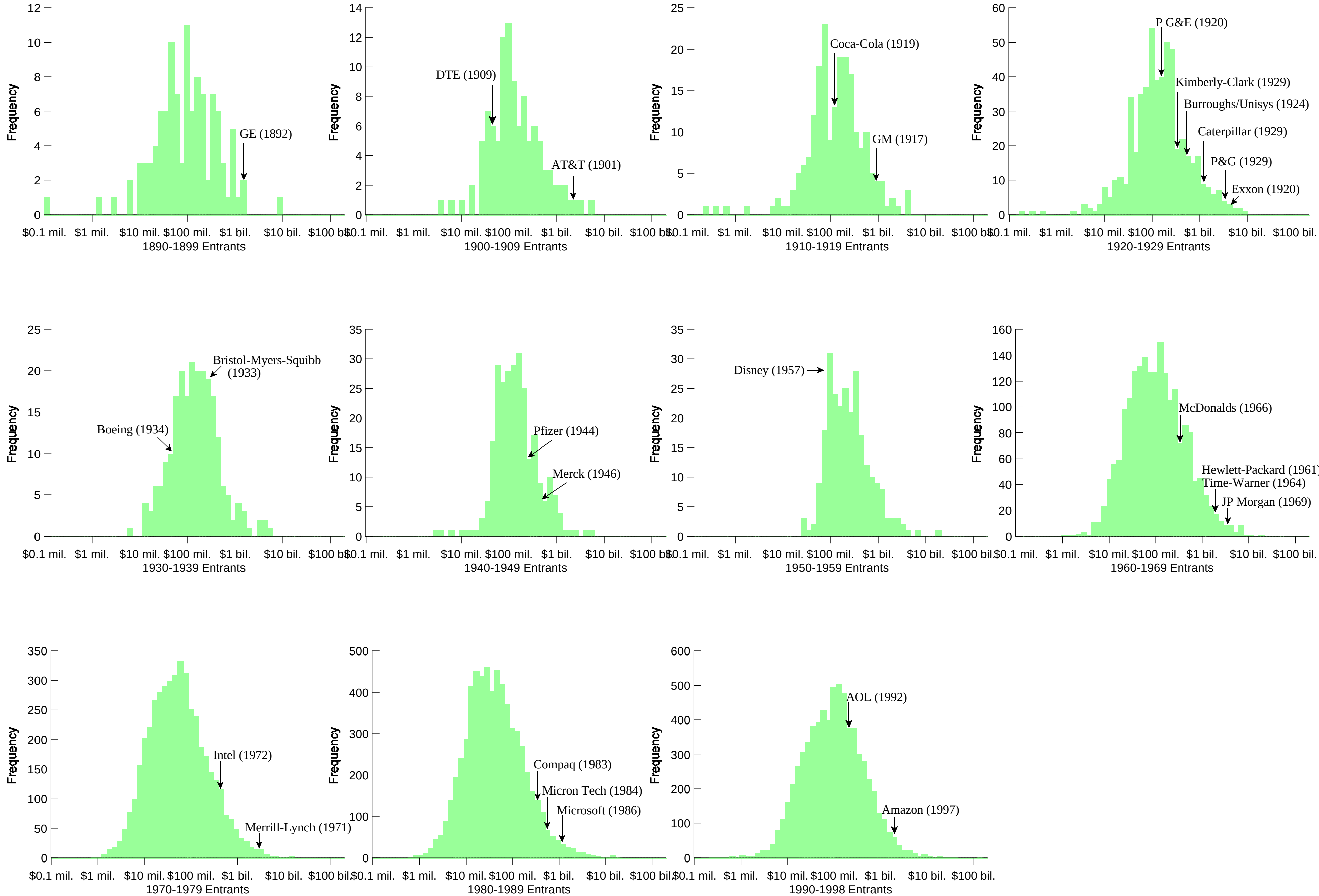

Figure 9: Size distributions for ten-year cross sections of entering firms, 1890-1998.

that successful firms will be more highly valued from the start than unsuccessful ones, many of which in fact (but not in the model) disband, the average 1998 value of surviving firms of earlier cohorts will be higher than those of later cohorts. This selection bias, when combined with estimates of $p_t^{\min}$ (see Figure 7) that are no larger in the 1890's than in 1998, tends to generate entry values for the early decades that are too large.[15]

There is reason to believe, however, that the selection bias is not too severe. Figure 9 presents histograms of entering firms pooled within decades that mark the entry positions of the firms that we featured in Figure 1. Most of the firms that ended up large and successful in 1998 had their value recognized in the market from the start. This is clear from the right-tail positions of most of these firms in the histograms, and offers additional support for our model. Firms that enter with good ideas and technologies do indeed seem to generate lasting value.

The second reason why we overpredict entry in the early years may have to do with the wage rate which, though it is a key part of the model, is held constant when computing π. While we cannot identify a good proxy for w_t, the existing literature on skill premia (i.e. Goldin and Katz 1999) show that the price of skilled labor was highest before 1915 and fell rapidly between 1915 and 1925. A large w_t would generate a larger π_t and reduce the amount of entry that the model predicts. Though our model has no role for the skill premium, it may still be the right proxy for w_t if one wants to predict lifetime returns on firms that are adopting a new technology, since skilled labor matters for adopting new technologies and less so for using old ones.

The third reason why we overpredict entry early on may be an inadequate adjustment for the quality of capital before 1907 and a consequent underestimate of the decline in the relative price of equipment in the early decades. Underestimating q leads to a J that is too low and, hence, a to a π and to a predicted entry that are too high for the 1890s.

6 Conclusions

The stock-market reveals large cohort effects in the surviving value of firms. Some cohorts of firms retain more value – per unit of investment and in the aggregate – than others. These vintage effects, or seeming quality differences among the cohorts, persist over long periods of time. They do not seem to reflect bubbles, Nor do they seem to be the result of merger waves or shifts between equity and debt finance.

We have argued that these differentials persist because technology grows in spurts, and because good technologies are appropriated by the new firms of their day. Firms sometimes do manage to redefine themselves by imitating the successful firms, by merging with them, by raiding their personnel, and so on. More often than not,

[15] In a related model Campbell (1998) analyzes this sort of bias.

however, such attempts fail, which is why, say, the 1970's cohort did not do as well as the 1960's cohort. Patents and other barriers do confer an advantage on first movers, and the advantages persist. Indeed, the inter-vintage value differentials persist over periods longer than the 18- or 20-year patent protection window. Our model asserts but does not explain why initial conditions should matter so much to the long-run value of the organization capital.

Finally, if vintage effects really do reflect technology, the data seem to show that the most successful implementors come in 15, 20 or even 30 years after a technological revolution has begun. The microprocessor dates back to 1971 but it isn't until 1986 that Apple and Microsoft first list on the stock exchange; the WW2 inventions took 20 years to materialize in the successful entrants of the late 1960s; the Niagara Falls hydroelectric dam was completed in 1895 which was the starting gun for the commercial-electricity era and yet the successful entrants did not come until 20 - 25 years after that. The long delay is a puzzle. A firm usually does begin producing output before it has its IPO, but, nevertheless, it is not until it lists on a stock exchange that the firm's idea gets implemented on a large scale.

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7 Appendix

Proof of Proposition 2 By "constant", we shall mean the value that a variable assumes on the balanced growth path. Since $H(s) = \frac{s^{1-\lambda}}{\lambda-1}$,

$$\gamma_H = \gamma_s^{1-\lambda} \tag{11}$$

From the evolution of k,

$$\gamma_k = 1 - \delta + \frac{qx}{k}, \tag{12}$$

c,y, x grows at the rate γ, and from (12), since $\frac{qx}{k}$ is constant,

$$\gamma\gamma_q = \gamma_k \tag{13}$$

From $Y = c + x + \phi n$, where $n = \int_s^\infty f(\varepsilon)\, d\varepsilon$ is the number of projects. Then

$$\gamma = \gamma_\phi \gamma_n \tag{14}$$

From $Y = A^{1-\alpha}\left(k^\eta h^{1-\eta}\right)^\alpha$,

$$\gamma = \gamma_A^{1-\alpha}\gamma_k^{\eta\alpha}\gamma_h^{(1-\eta)\alpha} \tag{15}$$

Substituting from (13) for γ_k,

$$\gamma = \gamma_A^{1-\alpha}\left(\gamma\gamma_q\right)^{\eta\alpha}\gamma_h^{(1-\eta)\alpha} = \left(\gamma_A^{1-\alpha}\gamma_q^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}\right)^{1/(1-\eta\alpha)} \tag{16}$$

Since $A' = A + \int_s^\infty z\varepsilon f(\varepsilon)\, d\varepsilon$, $\gamma_A = 1 + \frac{zH(s)}{A}$. Then $\frac{zH(s)}{A}$ is a constant so that

$$\gamma_z \gamma_H = \gamma_A. \tag{17}$$

Substituting from (17) into (16),

$$\gamma = \left(\left[\gamma_z\gamma_H\right]^{1-\alpha}\gamma_q^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}\right)^{1/(1-\eta\alpha)} \tag{18}$$

It remains for us to solve for γ_s, in terms of γ_ϕ using

$$\begin{aligned} 1 + r_t &= q_t\left(\alpha\left(\frac{k_{t+1}^\eta}{A_{t+1}}\right)^{\alpha-1} h_{t+1}^{(1-\eta)\alpha} + \frac{(1-\delta)}{q_{t+1}}\right) \\ &= \frac{z_t s_t}{\phi_t}\left((1-\alpha)\left(\frac{k_{t+1}^\eta}{A_{t+1}}\right)^{-\alpha} h_{t+1}^{(1-\eta)\alpha} + \frac{\phi_{t+1}}{z_{t+1}s_{t+1}}\right) \end{aligned}$$

and

$$1 + r = \frac{U'(c)}{\beta U'(c')} = \frac{1}{\beta}\gamma^\sigma.$$

Writing "-1" for date t, and omitting (for brevity) the subscript $t+1$, the above two equations combine into

$$\frac{1}{\beta}\gamma^{\sigma} = \alpha q_{-1}\left(\frac{k^{\eta}}{A}\right)^{\alpha-1} h^{(1-\eta)\alpha} + \frac{1-\delta}{\gamma_q} = \mu_{-1}\left((1-\alpha)\left(\frac{k^{\eta}}{A}\right)^{\alpha} h^{(1-\eta)\alpha} + \frac{1}{\mu}\right) \tag{19}$$

where $\mu = \frac{zs}{\phi}$, so that

$$\gamma_\mu = \frac{\gamma_z \gamma_s}{\gamma_\phi} \tag{20}$$

If we can solve the above two equations for γ_s we are done. The first of these equations implies that $q_{-1}\left(\frac{k^{\eta}}{A}\right)^{\alpha-1} h^{(1-\eta)\alpha}$ is a constant, which means that $qh^{(1-\eta)\alpha}$ grows as fast as $\left(\frac{k^{\eta}}{A}\right)^{1-\alpha}$, or that

$$\gamma_q \gamma_h^{(1-\eta)\alpha} = \frac{\gamma_k^{(1-\alpha)\eta}}{\gamma_A^{1-\alpha}}. \tag{21}$$

Now, by (13), $\gamma\gamma_q = \gamma_k$. The second equality in (19) implies that $\mu\left(\frac{k^{\eta}}{A}\right)^{\alpha} h^{(1-\eta)\alpha}$ is a constant, which means that,

$$\gamma_\mu = \frac{1}{\gamma_A^{-\alpha}\gamma_k^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}} = \frac{\gamma_A}{\gamma} = \frac{\gamma_z\gamma_H}{\gamma} = \frac{\gamma_z\gamma_s^{1-\lambda}}{\gamma} \tag{22}$$

where the second equality follows by (15) which states that $\gamma = \gamma_A^{1-\alpha}\gamma_k^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}$, the third equality stems from (17) which states that $\gamma_z\gamma_H = \gamma_A$, and the last equality follows because $H = \frac{s^{1-\lambda}}{\lambda-1}$. But (20) gives us

$$\gamma_s = \frac{\gamma_\phi}{\gamma_z}\gamma_\mu = \frac{\gamma_\phi}{\gamma_z}\frac{\gamma_z\gamma_s^{1-\lambda}}{\gamma} = \frac{\gamma_\phi\gamma_s^{1-\lambda}}{\gamma} = \left(\frac{\gamma_\phi}{\gamma}\right)^{1/\lambda} \tag{23}$$

where the second equality follows from (22). The last equality in (23) follows because

$$n = \int_s^{\infty} \varepsilon^{-1-\lambda} d\varepsilon = \frac{1}{\lambda}s^{-\lambda}$$

so that $\gamma_n = \gamma_s^{-\lambda}$. Substituting from (23) into (18) yields

$$\gamma = \left(\left[\gamma_z\gamma_H\right]^{1-\alpha}\gamma_q^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}\right)^{1/(1-\eta\alpha)} = \left(\left[\gamma_z\left(\frac{\gamma_\phi}{\gamma}\right)^{(1-\lambda)/\lambda}\right]^{1-\alpha}\gamma_q^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}\right)^{1/(1-\eta\alpha)}.$$

where we have used (11) which implies that $\gamma_H = \gamma_s^{1-\lambda} = \left(\frac{\gamma_\phi}{\gamma}\right)^{(1-\lambda)/\lambda}$ by (23). Multiplying through by γ raised to the power

$$\frac{(1-\lambda)(1-\alpha)}{\lambda(1-\eta\alpha)}$$

leads to an expression for γ raised to the power

$$\frac{\lambda(1-\eta\alpha)+(1-\lambda)(1-\alpha)}{\lambda(1-\eta\alpha)}=\frac{-\lambda\eta\alpha+\lambda\alpha+1-\alpha}{\lambda(1-\eta\alpha)}=\frac{\lambda\alpha(1-\eta)+1-\alpha}{\lambda(1-\eta\alpha)}$$

Simplifying then yields

$$\gamma=\left(\left[\gamma_z\gamma_\phi^{(1-\lambda)/\lambda}\right]^{1-\alpha}\gamma_q^{\eta\alpha}\gamma_h^{(1-\eta)\alpha}\right)^{\lambda/[\lambda\alpha(1-\eta)+1-\alpha]}$$

If $\eta=1$,

$$\gamma=\gamma_z^{\lambda}\gamma_\phi^{1-\lambda}\gamma_q^{\alpha\lambda/[1-\alpha]}$$

whereas, if $\eta=0$,

$$\gamma=\left(\left[\gamma_z\gamma_\phi^{(1-\lambda)/\lambda}\right]^{1-\alpha}\gamma_h^{\alpha}\right)^{\lambda/[\lambda\alpha+1-\alpha]}$$

Approximately,

$$g\approx\frac{\lambda}{\lambda\alpha(1-\eta)+1-\alpha}\left\{(1-\alpha)g_z+\eta\alpha g_q+\alpha(1-\eta)g_h+\frac{(1-\alpha)(1-\lambda)}{\lambda}g_\phi\right\}$$

If $\eta=1$

$$\begin{aligned}g&\approx\frac{\lambda}{1-\alpha}\left\{(1-\alpha)g_z+\alpha g_q+\frac{(1-\alpha)(1-\lambda)}{\lambda}g_\phi\right\}\\&=\lambda g_z+\frac{\alpha\lambda}{1-\alpha}g_q+(1-\lambda)g_\phi\end{aligned}$$

whereas, if $\eta=0$,

$$g\approx\frac{\lambda}{\lambda\alpha+1-\alpha}\left\{(1-\alpha)g_z+\alpha g_h+\frac{(1-\alpha)(1-\lambda)}{\lambda}g_\phi\right\}.$$

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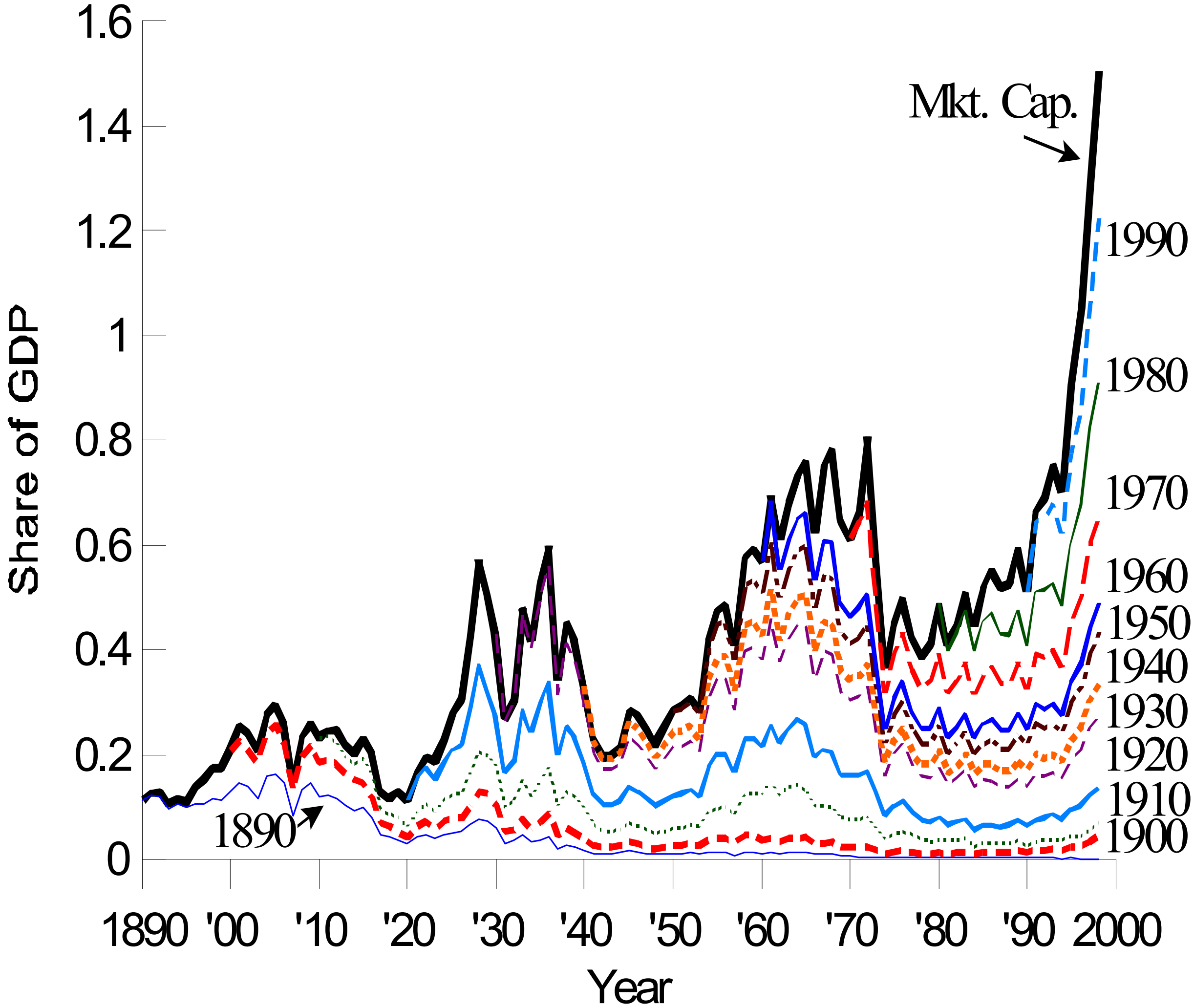

Figure 10: Shares of market capital retained by ten-year incumbents cohorts