TECHNOLOGY AND THE STOCK MARKET: 1885 - 1998

by

Boyan Jovanovic and Peter L. Rousseau

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DEPARTMENT OF ECONOMICS
VANDERBILT UNIVERSITY
NASHVILLE, TN 37235

www.vanderbilt.edu/econ

Technology and the Stock Market: 1885-1998

Boyan Jovanovic and Peter L. Rousseau*

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Abstract

Using 114 years of U.S. stock market data we relate movements in stock prices to changes in technology. We find

- Highly significant vintage effects in stock-price data that are especially strong in the 1920's. We interpret the vintage effects as shocks to organization capital,
- A rise in the productivity of organization capital at a rate of 1.9 % per year,
- A large shift to stocks and away from debt finance over the entire period,
- The smallest stock-market entrants have been getting smaller, probably because it is getting cheaper to go public, and
- Three major technological waves: The electricity wave (1895-1930) the "post-WW2" technological wave 1945 - 1970) and the IT wave (1971 - ...). The puzzle is that most value is created by firms that enter at the tail end of the waves.

1 Introduction

We study how technological change affects the economy and the stock market. We find that some vintages of entrants have far more surviving value than others. Relative to trend, the 1920's firms are the most remarkable on this score and this runs counter to the conventional view that the '20s were a time of exuberance and unsound investment. We also find that over the past century and, especially over the past 30 years, entrants seem to find it easier to list on one of the exchanges, and this has probably raised the speed with which the economy will absorb any new technologies that may arrive.

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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 4.53 percent

Some vintages retain a strong presence in 1998, even allowing for the volume 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 as a golden age – did not do as well as the 1920's.

In a one-sector world in which firms financed their initial investments entirely with stock-issues and replaced their capital as it wore out, the dashed lines and the solid lines would coincide. Why, then, does the solid line deviate from the dashed line?

[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 indices reported in the famous 1938 Cowles Commission's volume titled *Common Stock Prices Indexes*. We obtained firm book capitalizations from *Bradstreet's*, *The New York Times*, and *The Annalist*. The resulting dataset, though limited to annual observations, actually includes more common stocks than the CRSP files in 1925. Our study complements others that have begun to build a more complete view of securities prices in other markets during this period. See, for example, Rousseau (1999, 2000) on Boston's equity market.

[2]In raw form, Figure 1 would include large spikes in 1962 and 1972 that correspond to the years in which the AMEX and Nasdaq were added to CRSP. Since Nasdaq firms traded actively in over-the-counter prior to 1972 and AMEX's predecessor (the New York Curb Exchange) dates back to at least 1908, it is important to re-assign the capital of the AMEX and Nasdaq firms in these spikes to an approximation of the "true" entry years. We do not know the actual years in which the surviving 274 Nasdaq firms that entered CRSP in 1972 became active in OTC trading, but we have, however, identified the incorporation dates for 117 (42.7%) of them from the March 1999 edition of Standard and Poor's *Stock Report*. We also know incorporation dates for 907 (17.4%) of the 5,213 firms that entered CRSP/Nasdaq after 1972, and can thus 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. We do this by starting with 1971 and re-scaling the distribution of post-1972 differences to include only the relevant distances. For 1971, 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 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 13.38% 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 entry percentage for 1969-1971 of 1998 capital (1.72%) entered the sample in 1972 through NYSE or AMEX, leaving the differences (13.38%-1.72%=11.66%) to be re-distributed. We use a similar procedure to re-distribute the 1962 spike associated with AMEX's entry to CRSP.

[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.

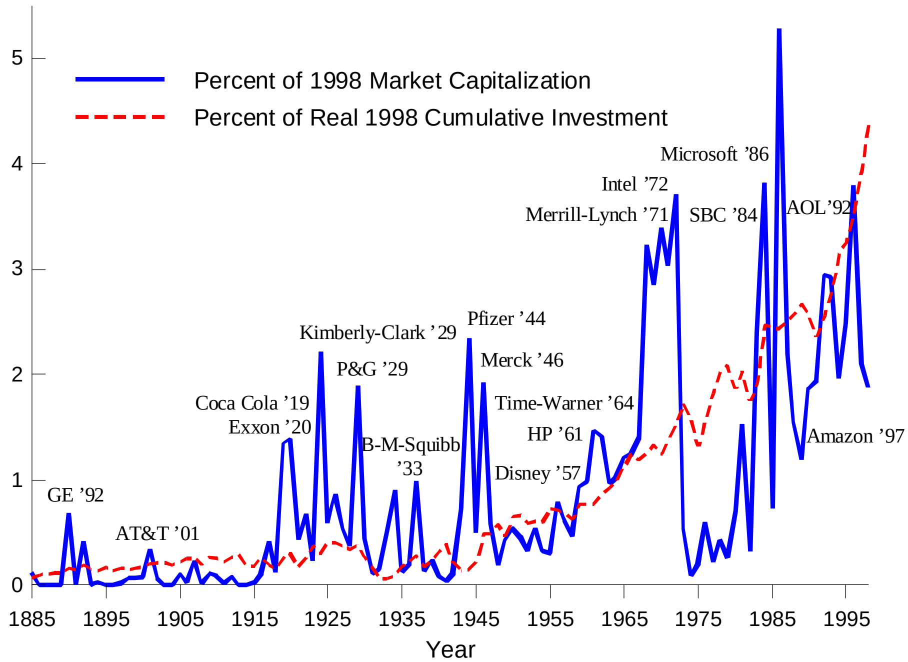

Figure 1: Annual U.S. gross investment and the 1998 value of all listed firms by year of listing.

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 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 good, some not so good, 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.[4] Some mergers may embody a decision by incumbents to redirect investment and re-deploy old capital

[4]We adjust Figure 1 for mergers using 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

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.

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. In justifying some of the assumptions, we implicitly 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 (Jovanovic and Rousseau, 2001, and reproduced as Figure A1 in the appendix). That is, if a firm today is overvalued relative to its fundamentals, it has more likely than not always been overvalued, and that would seem highly improbable. Finally, we do not know how much the last factor affects things.

Results From stock prices, we derive a series of estimates of the technology shock to firms' organization capital. The shock grows at about 1.9 percent per year but is more variable than the technology shocks extracted from productivity data or from information on the relative price of capital. Moreover, technology does not rise monotonically because a monotonic shock cannot produce a large dip in values of a vintage. We argue that a good technology is brought in and then appropriated by

1989 uncovered the acquirers for 3,646 (91.9%) of these unlinked mergers, 1803 of which turned out to be CRSP firms. Further, we 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.* With these source data, 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. The extent of the corrections suggest that any effects of mergers that remain unaccounted for would be small.

the entrants of the day, perhaps with the help of patents and technological secrecy, but we do not model these impediments to imitation.

The volatility of the estimated shock is not surprising considering that it is based primarily 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 that is far larger than one would expect based on reasonable adjustment costs of investment in 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.

Previous work on vintage effects by Johnson (1980) on workers' wages and by Levin and Stephan (1991) on physicists' research publications considers individuals 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. We have time effects, however, because the solid line in Figure 1 is a *cross-section* quantity and we use it to extract a 113-year series of technology estimates from the cross-section of 1998 prices of firms that entered the stock market at different times. That is, the volatility of these estimated shocks derives from relative stock-price volatility in 1998, and not time-series volatility. Moreover, 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), Hornstein and Krusell (1998). 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 its 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. This is the shock that will explain the puzzle displayed in Figure (1)

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 to something intuitive and estimable, we have sacrificed some realism. First, technology is exogenous. Second, trees do not absorb a maintenance fee, and so, as in the first-generation vintage capital model of Solow (1960), trees are not abandoned. Third, obsolescence of trees occurs only through interest-rate movements, an assumption that Hobijn and Jovanovic (2000) relax, and one that we entertain in a version of this paper that circulated last summer. Fourth, tree-quality is known before the tree is planted, an assumption that Jovanovic (1982) relaxes. Fifth, this is a perfect foresight model in which technological "shocks" are exogenous and perfectly foreseen.

2.0.2 Crusoe's decision problem

Each period, Crusoe spreads his capital among trees of all vintages 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:

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

We then have the aggregation result:

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, $Y = \left(\bar{\theta}\right)^{1-\alpha} (k^{\eta} h^{1-\eta})^{\alpha}$. 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

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

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 should decentralize easily. 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, 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. But the inframarginal trees are more rewarding.

Next, the factor market. The marginal product of capital is equated to the user cost of capital, 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 terms 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

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

The price of a tree is the 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 not 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 will be the starting point for the empirical work.

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 steadily, 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 2shows, 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 is rolled back.

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.

3.1 Vintage organization capital

Organization capital is whatever makes a collection of people and assets more productive together than apart. Firm-specific human capital (Becker 1962), management capital (Prescott and Visscher 1980), physical capital (Ramey and Shapiro 1996), and a cooperative disposition in the firm's 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. Moreover – and this is what

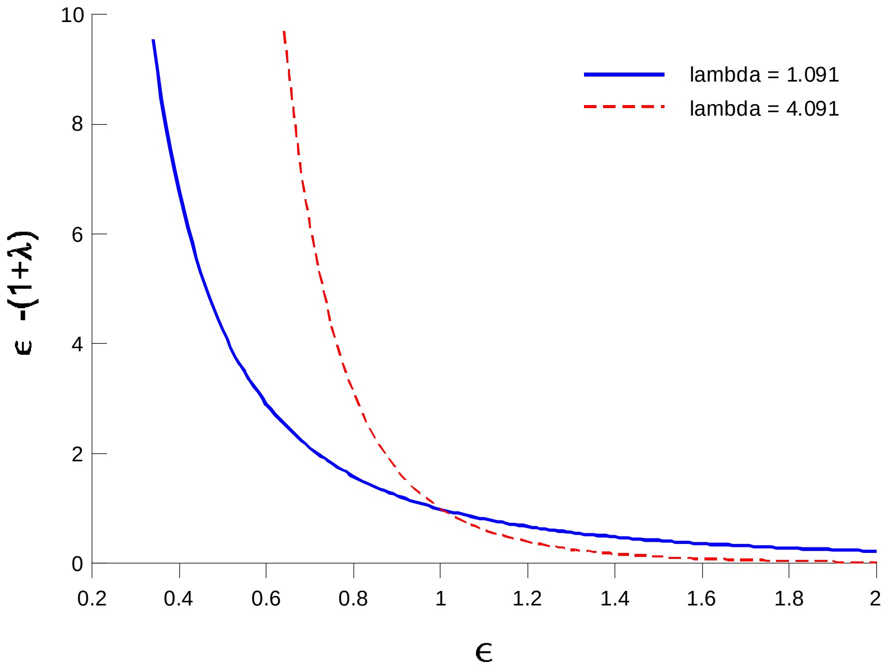

Figure 2: The Pareto Distribution.

matters here – the nature of organization capital will reflect conditions that prevailed at the time the firm 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 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 the imprint will persist if the organization capital is subject to adjustment costs. 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.

Organization capital differs from other intangibles because it is costly for other organizations to acquire. 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. How much of the firm's value derives from intangibles? One way to judge this is to look at the tangible assets that are included as part of a firm's book value. Figure 3, which is the frequency distribution of the ratio of market to book value for all 6,739 firms listed in the combined CRSP and

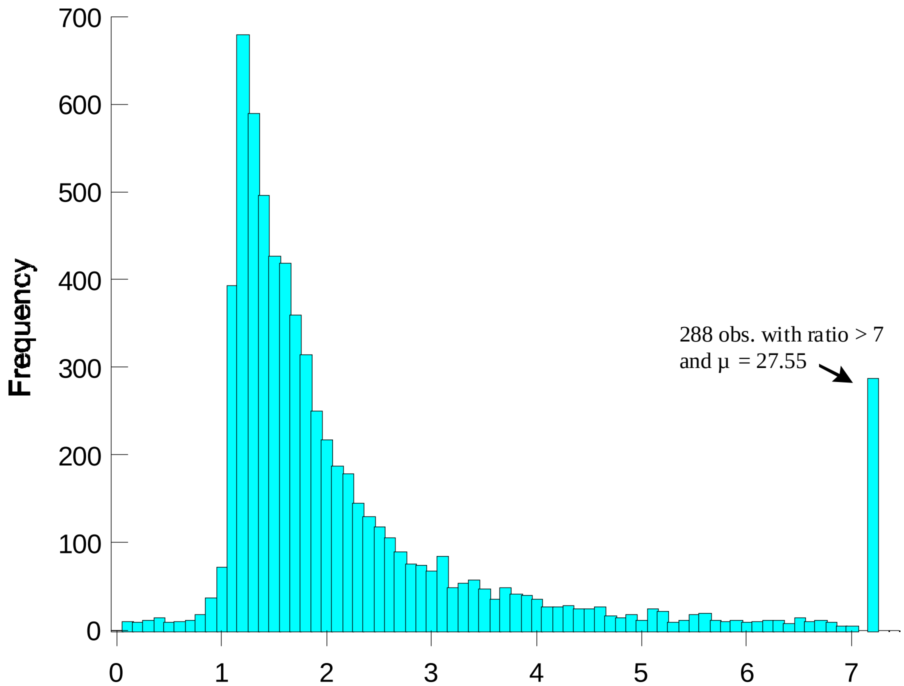

Figure 3: Ratio of market to book valuations for 1998 CRSP/Compustat firms.

Compustat files in 1998, shows just how often and widely market values can diverge from the value of the firm's assets at historical cost. Before proceeding, we explain why the median is not unity but 1.65, and then we explain why the ratio differs so widely among firms.

(i) *Why the median differs from unity*: From (6), the marginal product of capital is equated to the user cost of capital, J_t. That is,

$$\frac{k_{t+1}}{q_t} = \frac{\alpha\eta y_{t+1}}{1 + r_t - \frac{q_t(1-\delta)}{q_{t+1}}}$$

Assume that r is fixed, and take the simple case in which q is a constant, say at $q = 1$. Moreover, assume that ϕ is spending on underwriters, lawyers and brokers that does not get on the books as an asset. Then k and y would grow at the same rate and a firm with a capital stock of k would have a book value of

$$\frac{k}{q} = \frac{\alpha\eta y}{r+\delta}.$$

The market value of such a firm would be $(1-\alpha)\, y/r$ and so the market-to-book value of that firm would be

$$\frac{\text{market value}}{\text{book value}} = \frac{(1-\alpha)\,(r+\delta)}{r\alpha\eta},$$

which does not depend on a firm's ε or on its vintage. In other words, all firms would have the same market-to-book values. The 1998 median of the M/V distribution in Figure 3 is 1.65. If $\eta = 0.33$, $r = 0.055$, and $\delta = 0.125$, we should have

$$\frac{(1-\alpha)(r+\delta)}{r\alpha\eta} = 1.65, \text{ so that } \frac{\alpha}{1-\alpha} = \frac{(0.18)}{(1.65)(0.33)(0.055)},$$

which gives $\alpha = 0.86$, just a little below what one would expect.

(*ii*) *Why dispersion arises in Figure* (3): Dispersion among vintages arises if q grows over time. In that case, young firms have gotten more k per dollar spent, and their ratio of market to book value should be higher. Dispersion *within* vintages occurs if a part of ϕ shows up on the books. Large firms can spread this fixed cost over more output and their market-to-book values should be higher. One could derive this precisely but the long and the short of it is that young firms and large firms should be in the right tail of the distribution.

3.2 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,

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

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

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

We need to correct 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 the new firms raise their capital through the two kinds of borrowing 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. We do not explain this, but we try to account for it by interpreting the solid line in Figure 1 to be the ratio

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

This lets us solve for the sequence $\varphi_v = \frac{\xi_v z_v^{\lambda} \left(p_{98,v}^{\min}\right)^{1-\lambda}}{\sum_{v' \le 1998} \xi_{v'} z_{v'}^{\lambda} \left(p_{98,v'}^{\min}\right)^{1-\lambda}}$. 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.

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 would then, logically, use all the years together as follows:

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

From $\hat{\lambda}$ to the $\hat{z}$'s Having found $\hat{\lambda}$, we compute the series for the $\hat{z}$'s shown in Figure ·. 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, excluding any interpolated entries, implies an average growth rate of 1.9 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 through the use of $p_{\min}$.

4 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

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

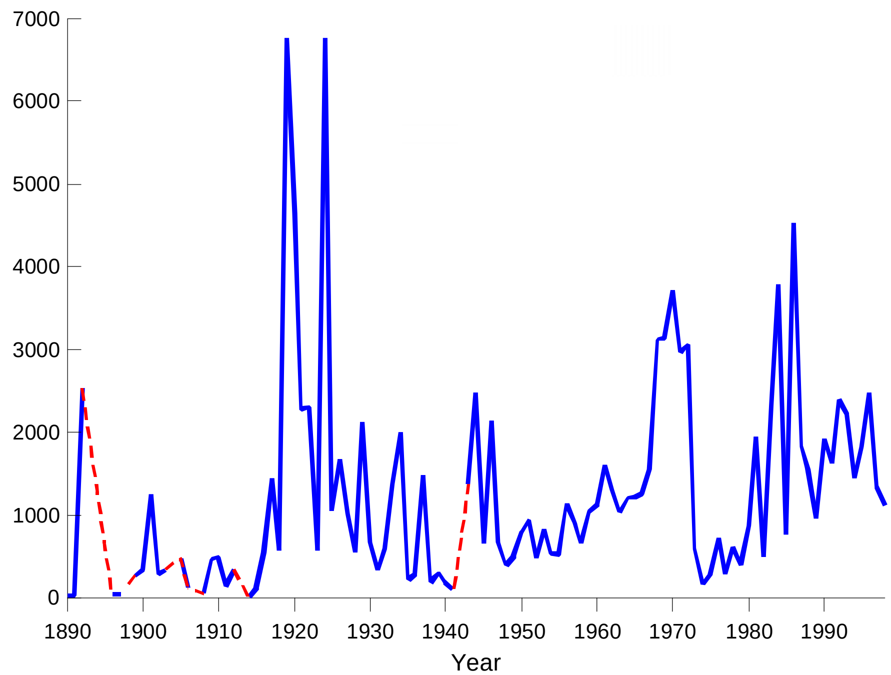

Figure 4: Estimates of z.

Total value created by date-t entrants is

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

Now we wish to report the densities by decade on an arithmetically-labelled log scale. Note that $p^{-(1+\lambda)} = \exp\left\{\ln\left[p^{-(1+\lambda)}\right]\right\} = \exp\left\{-(1+\lambda)\ln p\right\}$. Therefore substituting this into the previous equation and correcting for the share of equity in external finance for each entry year, we obtain the density of n_t on the $\ln p \equiv x$ axis

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

and this inderlies the solid lines in the figure.

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 5 presents the series.[5] Finally we need the model's prediction for

[5]The average firm size and average number of employees per business concern are also included in the figure. These plots show that the decline in entry size after 1960 was not simply the result of a tendency for businesses to downsize.

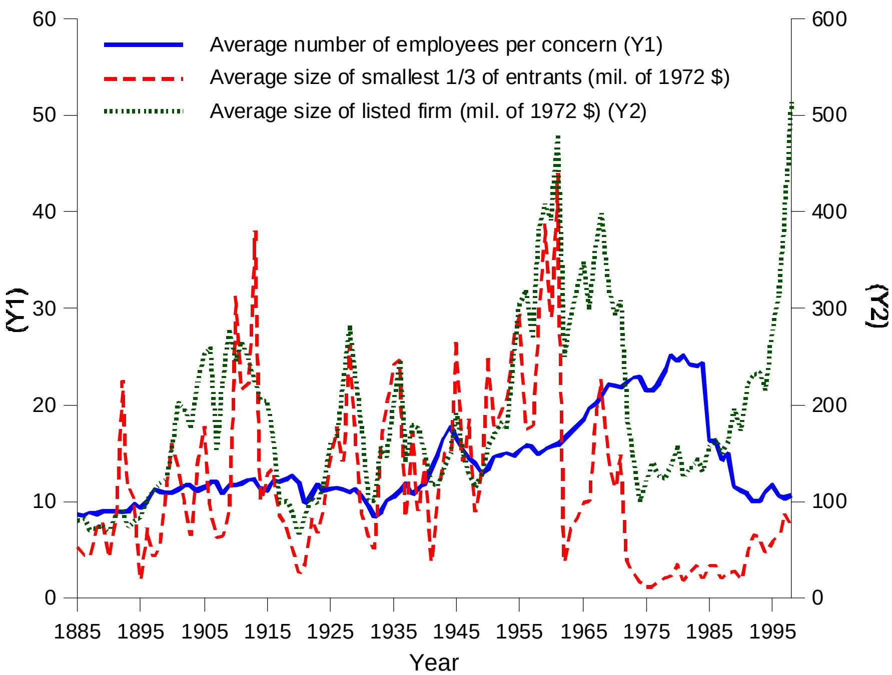

Figure 5: Characterizations of firm size.

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.[6] For w we would want the time-wage (wh) divided by h, but we do not have a reliable measure of h. The U.S. has had a lot of immigration over this period – less so in the middle, but most of it unskilled – and so it was probably skilled labor that was relatively scarce. We shall therefore use the skill premium as a proxy for w. Specifically, we combine Williamson's and Lindert's (1980) estimates of the wage ratio for urban skilled and unskilled workers for 1885-1894 with estimates from Goldin and Katz (1999) of the ratio of clerical to manufacturing production wages for 1895-1938 and the returns to 16 versus 12 years of schooling for men for 1939-1995.[7]

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 for 1963-1992 by using the consumer price index to deflate the

[6]We construct the consumption series from unpublished tables underlying Kuznets (1961) for 1885-1928 and the National Income and Product Accounts for 1929-1998.

[7]Combining several very different series into a continuous "skill premium" is necessary due to sectoral shifts in the skilled and unskilled labor forces that render particular measures of skill more applicable to some periods than others. For example, a college education appears to have become a more important determinant of income in the postwar period than it was in the earlier part of our sample. Since the Goldin and Katz observations are generally decadal, we interpolate between them to obtain an annual series for 1895 to 1995.

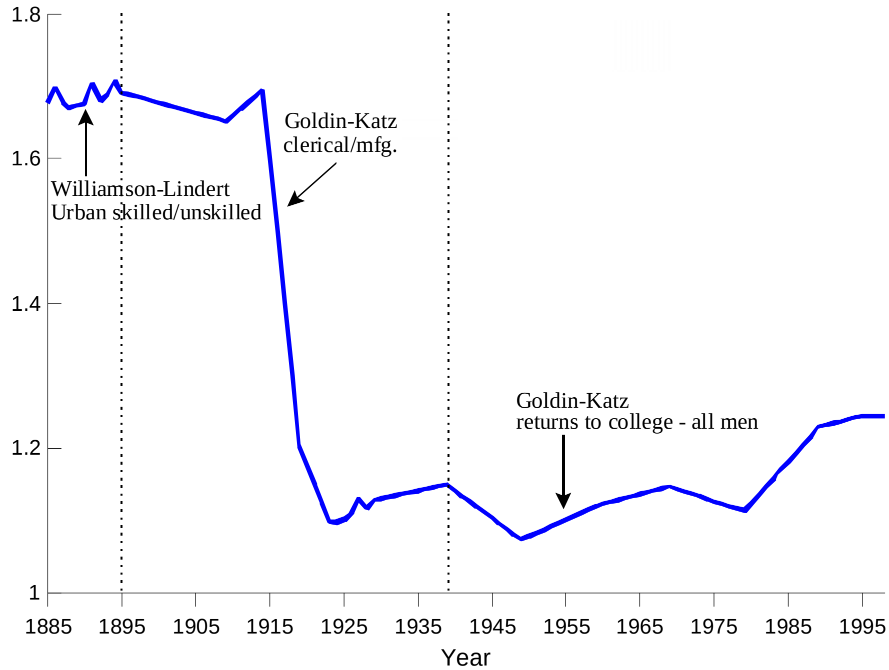

Figure 6: The skill premium.

quality-adjusted estimates of producer equipment prices from Gordon (1990, table 12.4, col. 2, p. 541), which are available from 1947 to 1983, and then using VAR forecasts to extend the result through 1992, and we will use this series. For 1947-1962, we deflate Gordon's series with an index for non-durable consumption goods prices that we derive from the National Income and Product Accounts (NIPA).

To build estimates for the pre-1947 period, we begin with the cross-country relation between real per capita income (y) and the relative price of capital (p^k) in 1980. The cross-country regression, using data from Jones (1994), is

$$\ln p^k_{i,1980} = const - 0.23 \ln y_{i,1980}$$

We then choose the constant so that the U.S. in 1947 is on the regression line, i.e.,

$$const - 0.23 \ln y_{US,1947} = p^k_{US,1947},$$

thereby 'splicing' the pre- and post 1947 series at that point. Next, we use per capita real GDP from the NIPA for 1929-1947 and from unpublished technical tables underlying Kuznets (1961) for 1870-1928 to backcast the trend of U.S. quality-adjusted relative equipment prices through 1870. A series of the relative prices of durable goods can also be constructed directly from the NIPA and Kuznets sources. This series has a gradual upward trend, presumably due to the lack of an adjustment for

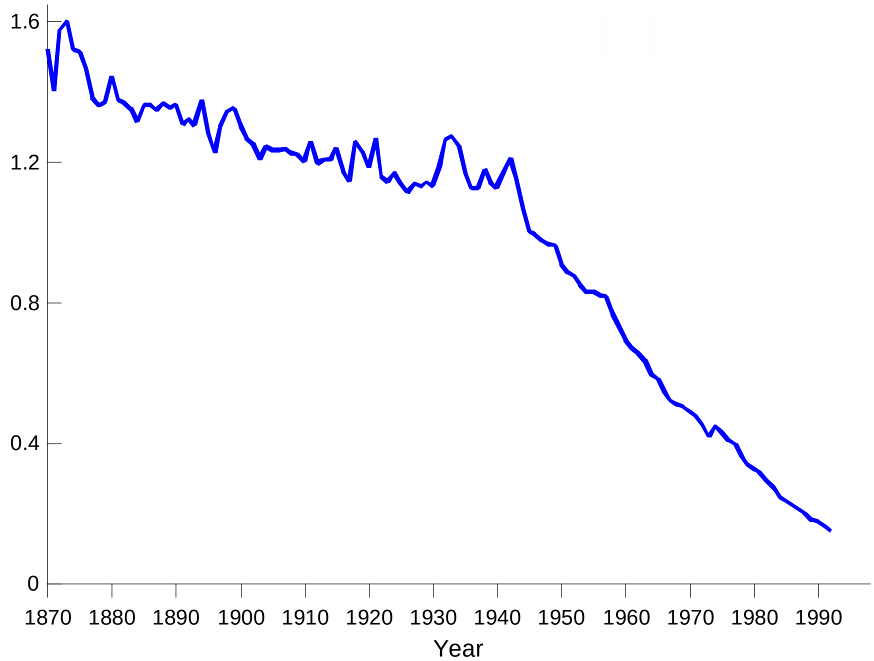

Figure 7: The relative price of equipment

quality. Nevertheless, the series might be expected to reflect fluctuations in relative prices reasonably well. To incorporate these fluctuations into our estimates, we subtract the unadjusted NIPA/Kuznets series from our initial backcast, apply the Hodrick-Prescott (1980) filter to the result, and add the residuals from the filter to the backcasted series. Figure 7 presents our final estimates of quality-adjusted relative equipment prices.

In applying this technique, we are assuming that the relative price of equipment in the U.S. in 1900, say, was in the bottom twenty percent of the world's countries. In fact, with a relative price of equipment about four times higher in 1900 than in 1980, the U.S. across time has differences similar to those between the U.S. in the 1980 cross-section and Pakistan, the Philippines, or Peru. Why, then, do we think that there is any relation between the two sets of numbers? Two points in favor: First, the quality adjustment is more uniform, we think, in the Jones data than it is in the NIPA/Kuznets figures, although there is some quality-bias in the cross-country data as well (i.e., the U.S. uses better tractors than Zimbabwe and their price is higher). Second, if these countries were at the same stage of development, they would perhaps want capital goods that do similar things. On the other hand, the poor countries in 1980 used older capital than the advanced countries, but certainly newer vintages of capital than were in use in the U.S. in 1900. If quality adjustment is imperfect, this will make the 1900 estimate for the U.S. too low, and thus creates a downward bias in our relative price estimates the farther back we go. On these grounds, we should be adjusting the NIPA/Kuznets numbers even more upward than we do.

With the model calibrated, we pool the data in each decade, generate histograms of real firm entry size, and display them in Figure 8. We then superimpose the vertical addition of the predicted densities upon these histograms.[8] We should note, however, that the predicted distributions 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.

To assess the model's ability to predict the market values of cohorts upon entry to the market as well as their numbers, we next compare $N_t\left(p_t^{\min}\right)$ and $\hat{V}_t$ to the observed quantities by decade. Table 1 shows that the model generally underpredicts the amount of new capital that enters the market in each year

Table 1: Goodness of Fit

	Number of Firms			Value Entrants (bil. 1998$)		
	Model	Data	%	Model	Data	%
1890-99	378	550	-31.3	48.7	152.5	-68.1
1900-09	116	540	-78.4	46.1	175.5	-73.7
1910-19	1067	1040	+2.6	241.8	301.5	-19.8
1920-29	4748	2715	+74.9	864.8	1007.1	-14.1
1930-39	557	1140	-51.2	197.3	342.9	-42.5
1940-49	373	1355	-72.5	1771.8	3436.1	-48.4
1950-59	111	1270	-91.3	89.5	599.4	-85.1
1960-69	1914	10040	-80.9	559.3	3056.3	-81.7
1970-79	16120	22585	-28.6	1437.8	3820.7	-62.4
1980-89	55340	31610	+75.1	5211.0	4695.8	+11.0
1990-99	26770	34650	-22.7	3798.2	11028.2	-65.6

We have reduced the value that the model predicts for the early cohorts by using a w series that tracks the skill premium – Figure (6). That series shows labor getting much cheaper after 1914. Though not implied by the model, this measure may be the right one if one wants to predict lifetime returns on firms that are adopting a new technology. Skilled labor matters for adopting new technologies and less so for using old ones. The use of this labor cost series helped us predict the initial entering values somewhat better, yet now we end up underpredicting the early entering values. Another factor helping us is the secular rise in the user cost of capital implied by the increasing downward slope of the relative price of capital in Figure (7) but, quantitatively, this does not affect the predictions that much because the decline in the price of capital is but one component of the user cost of capital and because the share of capital is half that of labor. Nevertheless, it would have been as disastrous

[8]We adjust the eleven predicted densities displayed in Figure 8 by setting the sum of the areas beneath them equal to the total area under the actual histograms.

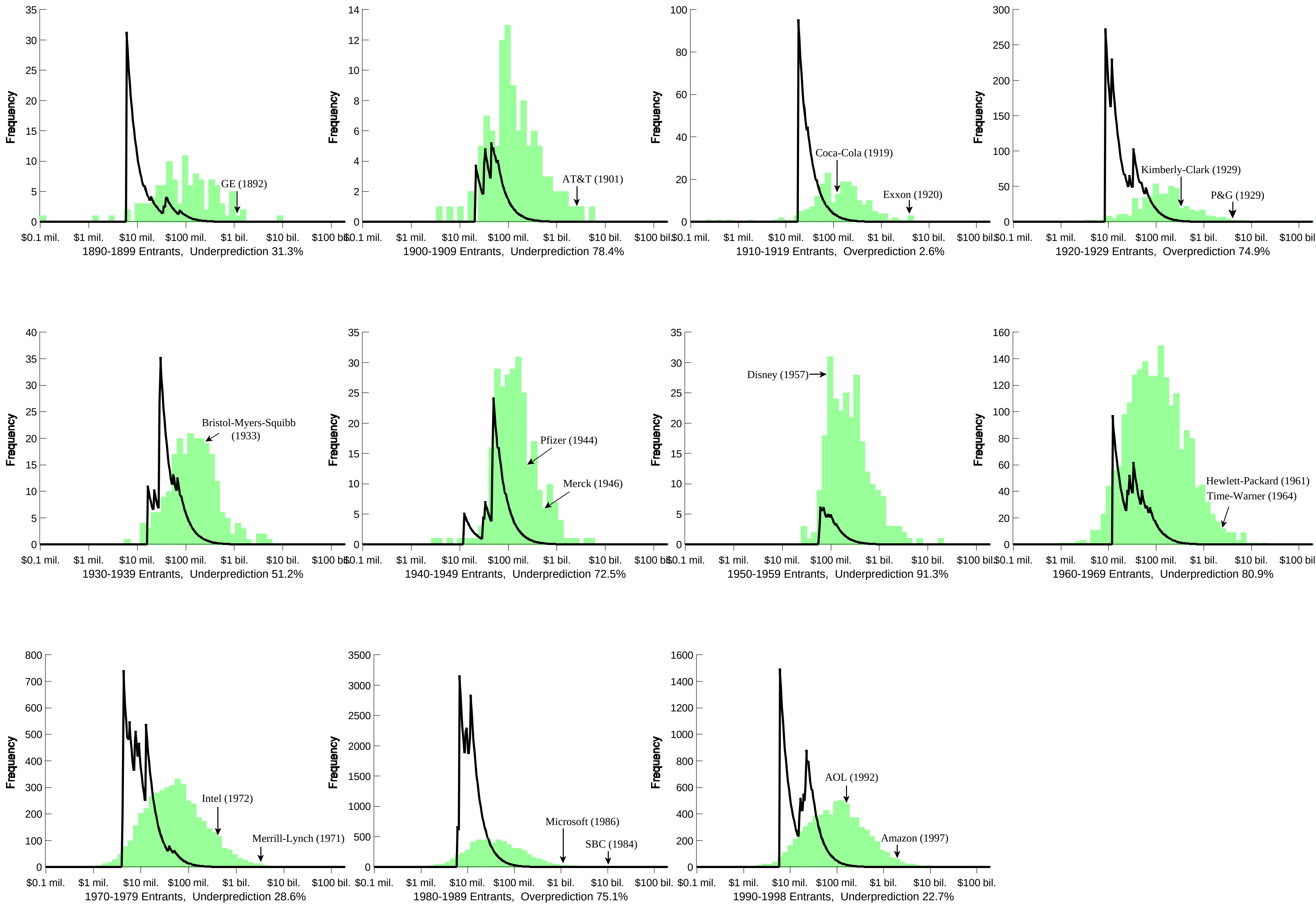

Figure 8: Size distributions for ten-year cross sections of entering firms, 1890-1998.

as it would have been inappropriate to use the standard pre-war estimates of the relative price of capital.

5 Conclusions

One hundred and thirteen years of stock-market data reveal large vintage effects in the quality of firms. Some cohorts of firms appear to be more valuable, per unit of investment and in the aggregate, than others. These vintage effects, or quality differences among the cohorts, persist over long periods of time and are not likely to reflect noise or bubbles. Nor do they seem to be the result of merger waves or shifts between equity and debt finance.

We argue that these differentials persist because organization capital is costly to adjust. Indeed, the model assumes that it is infinitely costly except through merger. Now, in fact, it is not impossible for firms in the bad cohorts to become like the firms in the good cohorts, and we see firms trying to redefine themselves by imitating the successful firms, by merging with them, by raiding their personnel, and so on. Nevertheless, the costs of adjustment of organization capital must be large; if they were not, we would not be seeing such large vintage effects in the values of stocks.

If the quality of organization capital does vary substantially over vintages, then this has some interesting consequences. First, it implies that imitation must be relatively hard. For, if it were easy, the firms born, say, in the 1970's should have done as well as firms born in the 1960's. It appears, though, that the technological laggard does not have such an easy time. The near-first movers on a technology do well relative to latecomers. That may be why Europe is having trouble reproducing the successes of the U.S. high-tech sector. One would like to know how the firms born in the '20s fared on world markets and how much of a development lead the U.S. got through the success of those vintages. Implicitly, we are finding that because of patents or other barriers to imitation, first mover advantages persist. The stability of the inter-vintage value differentials persists over periods of time longer than the 18- or 20-year patent protection window. It seems that initial success feeds on itself and so, therefore, does its absence. Our model asserts this much when we say that a firm can tend only one tree and cannot switch trees, but this leads to the unanswered question of why initial conditions should matter so much to the long-run value of the organization capital of U.S. firms.

Finally, if our interpretation of the vintage effects is true, we have another puzzle. The puzzle is not that value is created as late as 20 or 30 years after the technological revolution has begun. Rather, the puzzle is that value is not created earlier in the technological cycle. Figure **??** shows the average number of years between incorporation and exchange listing for 3,500 of the firms included on CRSP in 1998 by year of listing The successful cohorts are not the very first but, rather, the later waves of entrants and the gestation period for the birth of the successes is as long as 15 or even 20 years. The microprocessor is dated to 1971 but it isn't until 1986 that

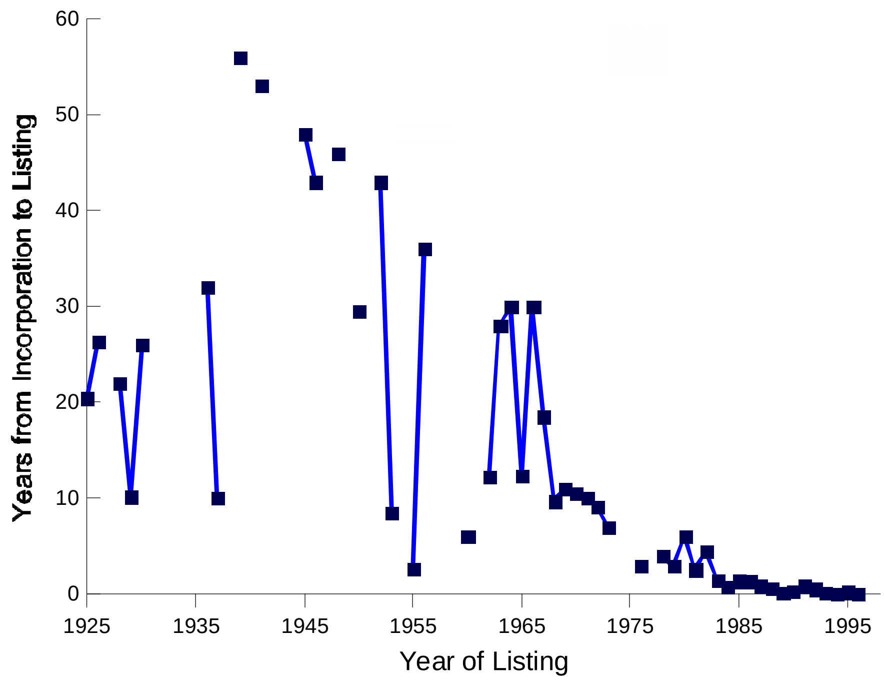

Figure 9: Waiting times from incorporation to exchange listing by year of listing

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. Finally, Niagara Falls was completed in 1895 which many would say is the starting gun for the commercial-electricity era and yet the successful entrants did not come until 20 - 25 years after that. The delays may partly be illusory since many firms do incorporate years before they first list on the exchanges, but, nevertheless, it is on its first-listing date that a firm really cashes in on its success.

References

[1] *The Annalist.* New York: The New York Times Co., 1912-1928, various issues.

[2] Atkeson, Andrew, and Patrick Kehoe "Industry Evolution and Transition: A Neoclassical Benchmark" *NBER* WP #6005, April 1997.

[3] Becker, Gary. "Investment in Human Capital: A Theoretical Analysis" *Journal of Political Economy* 70, no. 5, part 2 (October 1962): 9-49.

[4] *Bradstreet's.* New York: Bradstreet Co., 1885-1928, various issues.

[5] Carroll, Glenn, and Michael Hannan. *The Demography of Corporations and Industries.* Princeton: Princeton University Press, 2000.

[6] Cooley, Thomas, Jeremy Greenwood, and Mehmet Yorukoglu. "The Replacement Problem." *Journal of Monetary Economics* 1998.

[7] *The Commercial and Financial Chronicle.* 1885-1928, various issues.

[8] Cowles, Alfred and Associates. *Common Stock Price Indexes, Cowles Commission for Research in Economics Monograph No. 3.* Second Edition. Bloomington, IN: Principia Press, 1939.

[9] De Long, Bradford and Andrei Shleifer. "The Stock Market Bubble of 1929: Evidence from Closed-end Mutual Funds." *Journal of Economic History* 51, no. 3. (September 1991): 675 - 700.

[10] Eeckhout, Jan. "Competing Norms of Cooperation." University of Pennsylvania, January 2000.

[11] Evanson, David, and Art Beroff. "Going Public Goes High-Tech." *Entrepreneur* (April 2000): 88 - 91.

[12] Financial Information Inc., *Annual Guide to Stocks: Directory of Obsolete Securities.* Jersey City, NJ: Financial Information Inc, 2000.

[13] Gerdes, Geoffrey. *The Construction and Performance of Vintage Portfolios on the NYSE, 1926-1996.* Ph.D. Dissertation, Department of Economics, UCLA, 1999.

[14] Goldin, Claudia, and Lawrence Katz "The Returns to Skill in the United States across the Twentieth Century" *NBER* WP #7126, May 1999.

[15] Gordon, Robert *The Measurement of Durable Goods Prices.* Chicago, IL: University of Chicago Press, 1990.

[16] Gort, Michael, Jeremy Greenwood, and Peter Rupert. "Measuring the Rate of Technological Progress in Structures." *Review of Economic Dynamics* 2 (1999): 207-230.

[17] Greenwood, Jeremy, and Mehmet Yorukoglu. "1974." *Carnegie-Rochester Series in Public Policy*, 1997.

[18] Greenwood, Jeremy, and Boyan Jovanovic. "The Information-Technology Revolution and the Stock Market." *American Economic Association* (Papers and Proceedings) 89, no. 2 (May 1999): 116 - 122.

[19] Grossman, Sanford, and Robert Shiller. "The Determinants of the Variability of Stock Market Prices." *American Economic Review* 71 (1981): 222-227.

[20] Hayashi, Fumio. "Tobin's Marginal q and Average q: A Neoclassical Interpretation." *Econometrica* 50, no. 1. (January 1982): 213 - 224.

[21] Helpman, Elhanan, and Manuel Trajtenberg. "A Time to Sow and a Time to Reap: Growth Based on General Purpose Technologies." in *General Purpose Technologies and Economic Growth*, E. Helpman ed., MIT Press, 1998, 55-84.

[22] Hickman, Braddock. "Trends and Cycles in Corporate Bond Financing." NBER Occasional Paper #37, 1952.

[23] Hobijn, Bart, and Boyan Jovanovic. "The Information-Technology Revolution and the Stock Market: Preliminary Evidence." August 1999.

[24] Hodrick, R., and Edward C. Prescott "Postwar U.S. Business Cycles." Carnegie-Mellon University working paper, reproduced, 1980.

[25] Johnson, William. "Vintage Effects in the Earnings of White American Men." *Review of Economics and Statistics* 62, no. 3. (August 1980): 399 - 407.

[26] Jovanovic, Boyan. "Selection and the Evolution of Industry." *Econometrica* May 1982.

[27] Jones, Charles I. "Economic Growth and the Relative Price of Capital." Journal of Monetary Economics 34, no. 3 (December 1994): 359-382.

[28] Kendrick, John. *Productivity Trends in the United States*, Princeton University Press, 1961.

[29] Krusell, Per, Lee E. Ohanian, Jose-Victor Rios-Rull, and Giovanni L. Violante. "Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis." *Econometrica* 68, no. 5. (September 2000): 1029-1053.

[30] Kuznets, Simon S. *Capital in the American Economy: Its Formation and Financing.* Princeton, NJ: Princeton University Press, 1961.

[31] Levin, Sharon, and Paula Stephan. "Research Productivity Over the Life Cycle: Evidence for Academic Scientists." *American Economic Review* 81, no. 1 (March 1991): 114 - 132.

[32] Lucas, Robert E., Jr. "Asset Prices in an Exchange Economy." *Econometrica* 46, no. 6 (November 1978): 1429 - 1445.

[33] Nelson, Ralph. *Merger Movements in American Industry*, 1895-1956 . Princeton University Press for *NBER*, 1959.

[34] *The New York Times.* 1897-1928, various issues.

[35] Pakes, Ariel. "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks." *Econometrica* 54, no. 4. (July 1986): 755-784.

[36] Predicasts, Inc. *F&S Index of Corporate Change* Vols 5-25 (1969-1989).

[37] Prescott, Edward, and Michael Visscher "Organization Capital" *Journal of Political Economy* 88, no. 3 (June 1980): 446 - 461.

[38] Ramey, Valerie, and Matthew Shapiro, "Sectoral Mobility of Capital: A Case Study of an Aerospace Firm," University of Michigan, November 1996.

[39] Rob, Rafael, and Peter Zemsky. "Cooperation, Corporate Culture and Incentive Intensity." INSEAD WP# 9751 1997.

[40] Rousseau, Peter L. "The Boston Market for Banking and Industrial Equities, 1835-1897." *Historical Methods* 33:3, (Summer 2000): 163-169.

[41] Rousseau, Peter L. "Share Liquidity and Industrial Growth in an Emerging Market: The Case of New England, 1854-1897" *NBER* Historical Paper No. 103, March 1999.

[42] Solow, Robert. "Investment in Technological Progress." in Arrow, Karlin, and Suppes, eds., *Mathematical Methods in the Social Sciences*. Stanford, CA., Stanford University Press, 1960.

[43] U.S. Bureau of the Census. *Historical Statistics of the United States: Colonial Times to 1970.* Washington, DC: U.S. Government Printing Office, 1975.

[44] U.S. Bureau of the Census. *Statistical Abstract of the United States.* Washington, DC: U.S. Government Printing Office, various issues.

[45] Williamson, Jeffrey G., and Peter H. Lindert. *American Inequality: A Macroeconomic History*, New York: Academic Press, 1980.

6 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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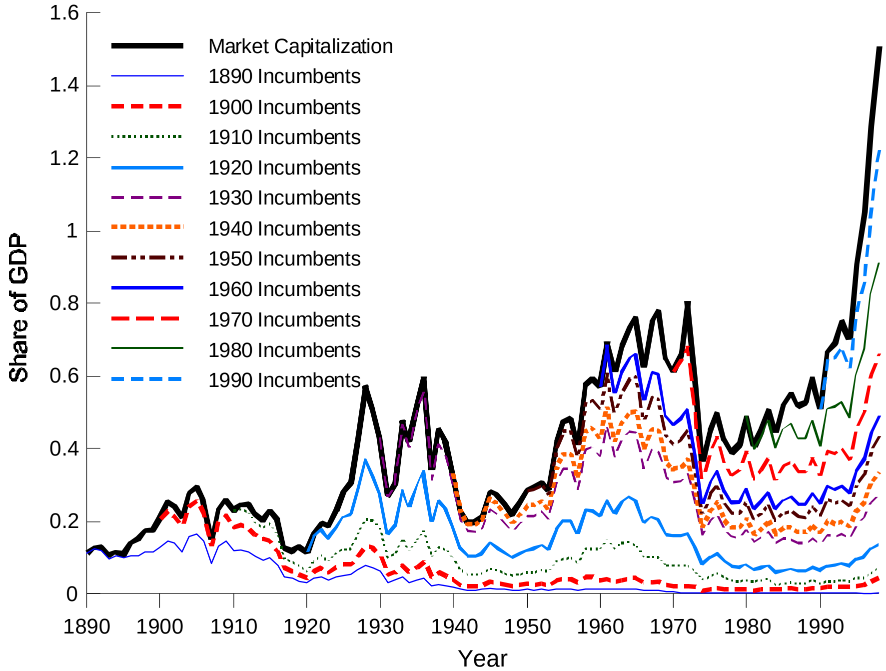

Figure 10: Shares of market capital retained by ten-year incumbents cohorts

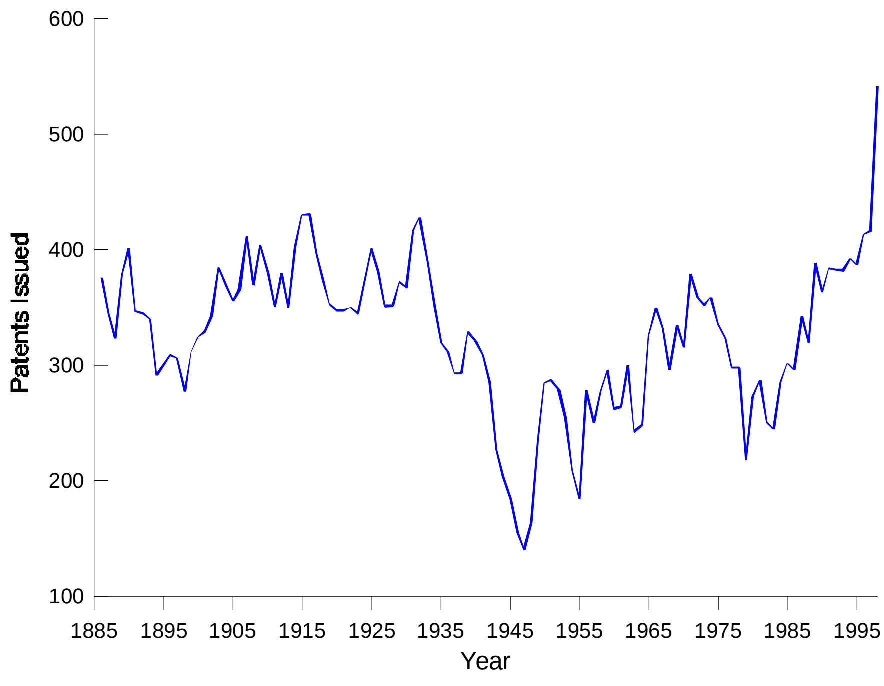

Figure 11: Patents issued per million persons

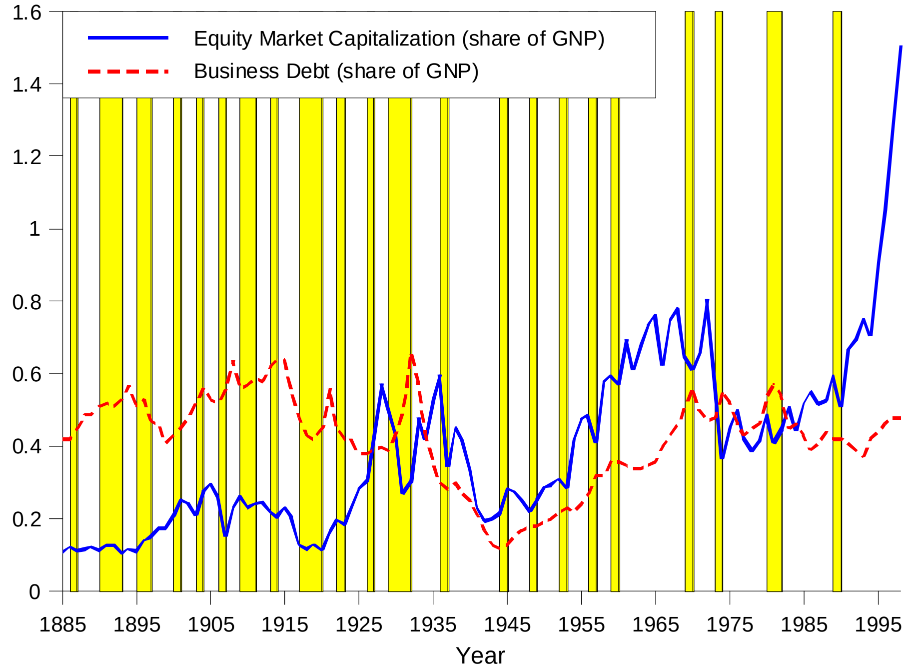

Figure 12: Ratios of market capitalization and debt to GNP