IPOs in the 20s

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Abstract

We build a model of technological change in which embodied technologies are adopted with greater delay than disembodied ones, and use it to explain the inverted U-shaped pattern of waiting times from firm founding and incorporation to initial public offering on the U.S. stock market over the past century.

1 Introduction

The 1920s were at the height and perhaps the tail end of the implementation of electricity and internal combustion. In that way they are comparable to the 1990s, which were at the height and perhaps the tail end of the computerization of the U.S. economy. Moreover, both decades contain stock market booms and IPO waves.

There was one important difference between the two decades, however, namely the age of the firms that went public. While the age of IPO-ing firms were approaching their all-time lows in the 1990s, the age of IPO-ing firms was rising in the 20s. That rise continued through the 1950s before beginning a rapid descent around the time that Information Technology (IT) arrived as dominant force in the 1970s. Figure 1 demonstrates these facts documented by Jovanovic and Rousseau (2001a), with the periods of the electrification and IT revolutions as dated by Jovanovic and Rousseau (2005) shaded.[1] Table 1 shows that the coverage in Figure 1 is remarkably good,

[1] Figure 1 shows HP-filtered average waiting times from founding and incorporation to exchange listing based upon individual company histories and our backward extension of the University of Chicago's Center for Research in Securities Prices (CRSP) database. Data and methods for this backward extension are described in Jovanovic and Rousseau (2001b). Listing years after 1925 are those for which firms enter CRSP. For 1890-1924, they are years in which prices first appear in the NYSE listings of *The Annalist, Bradstreet's*, *The Commercial and Financial Chronicle*, or *The New York Times*. Incorporation dates are from *Moody's Industrial Manual* (1920, 1928, 1955, 1980), Standard and Poor's *Stock Market Encyclopedia* (1981, 1988, 2000), and various editions of Standard and Poor's *Stock Reports*. The 4,221 foundings are from Dun and Bradstreet's *Million Dollar Directory* (2003), Moody's, Etna M. Kelley (1954), and individual company websites. We linearly interpolate the series between missing points before applying the HP-filter.

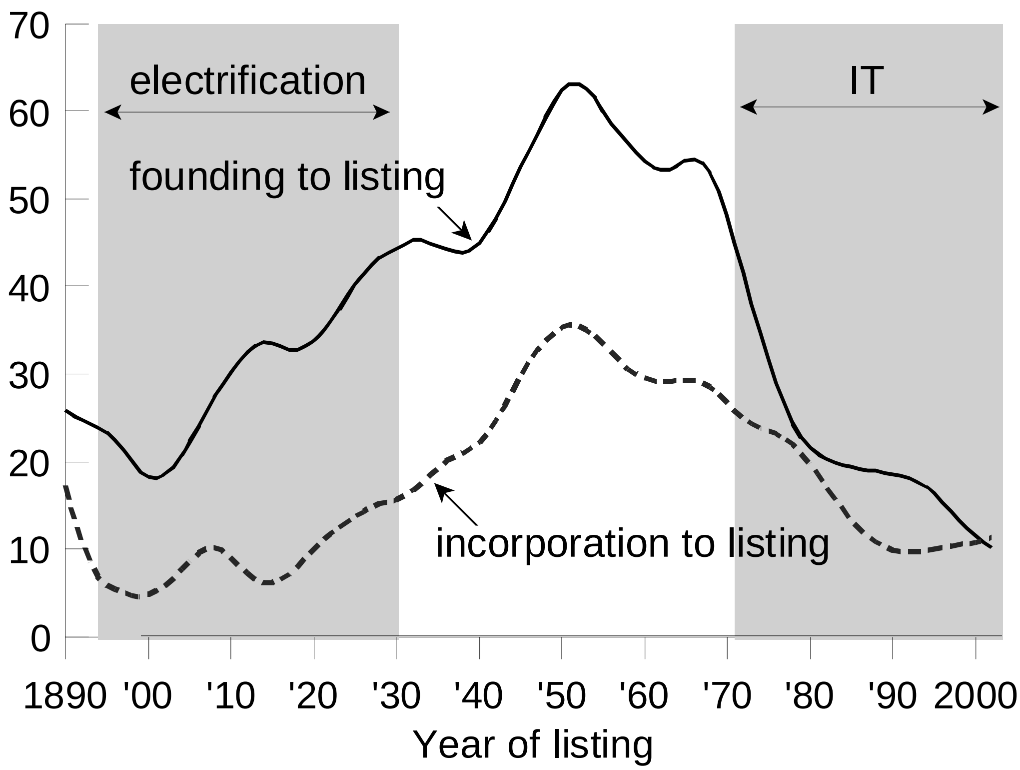

Figure 1: Waiting times (in years) to exchange listing, 1890-2002.

especially for incorporation dates in the first 60 years depicted. This ensures that the rise in waiting times from 1915 through 1950 is not an artifact of sample selection.

Why the rise in age of IPOs of the 1920's? More generally, why do we see the IPO age keep rising through the first half of the century? That is the question we shall address. Figure 2 suggests that it is implausible to attribute the rise to financial regress in the first half of the twentieth century.[2] This is because the ratio of the stock of broadly-defined money (M2) to gross domestic product was rising throughout the 1920s, and indeed had seen an upward trend since 1890. Further, stock market value as a share of GDP, though declining with the onset of the Great Depression, was also in a boom throughout the 1920s that is reminiscent of the run-up of the 1990s. So

[2] The money stock includes "money and quasi- money" from the 2007 edition of the World Bank's *World Development Indicators* database for 1960-2006, and is from Balke and Gordon (1986, table 1, pp. 784-6) for 1890-1959. Stock market value is the sum of end-of-year market values of all common stocks listed on CRSP for 1925-2006 and our backward extension of CRSP for 1885-1924. The GDP series is from the Bureau of Economic Analysis (2007) for 1929-2006 and from Kendrick (1961, table A-IIb, pp. 296-7) for 1890-1928.

Table 1–Number of Firms in the Waiting-Time Sample

Decade	All New Listings	Included Incorporations	Coverage (%)	Included Foundings	Coverage (%)
1890's	112	52	46.4	41	36.6
1900's	112	78	69.6	44	39.3
1910's	214	190	88.8	97	45.3
1920's	545	492	90.3	273	50.1
1930's	231	197	85.3	78	33.8
1940's	271	246	90.8	97	35.8
1950's	254	241	94.1	78	30.7
1960's	2,008	964	48.0	198	9.9
1970's	4,517	1,405	31.1	262	5.8
1980's	6,322	904	14.3	790	12.5
1990's	6,930	1,469	21.2	1,869	26.7
Totals	21,516	6,238	29.0	3,827	17.8

the 1920s were a period of rapid financial *development* rather than regression. Therefore another answer is needed. In looking for one, we need to consider the reasons why firms have IPOs. There are two primary motives:

1. Raising capital to finance expansion. Chemmanur, He and Nandy (2005, Figure 3) show that a firm's investment rises by the non-trivial factor of 1.4 around the time of IPO ($\pm$ 2 years), which means that IPOs also measure a rise in investment.

2. 'Exiting' so as to unload risk or to focus on other things. Venture funds offer high returns and Jovanovic and Szentes (2007) argue that this forces venture capitalists (VCs) to be especially eager to unload to the market-at-large the stakes they hold in their portfolio companies.

Our model will emphasize the first motive – that of raising money – but we shall not explain why the firm cannot borrow as much as it ever needs at the going rate of interest. We have, in other words, no theory of finance in this paper. We shall instead concentrate on drawing out the implications for two types of technological change: Specific to a firm vintage, and disembodied. We shall then consider another explanation based on capital endowments of various vintages of firms.

We wish to explore the possibility that the difference between the 20s and the 90s shown in Figure 1 originates in the different nature of technological change. In the IT era, many new companies are based on ideas and information and less on physical capital. As knowledge advances, companies can more easily absorb it and adapt to it than was true 100 years ago. In the electrification era, technological change may have been harder to implement once the plant was built and once the original concept of the firm was in place.

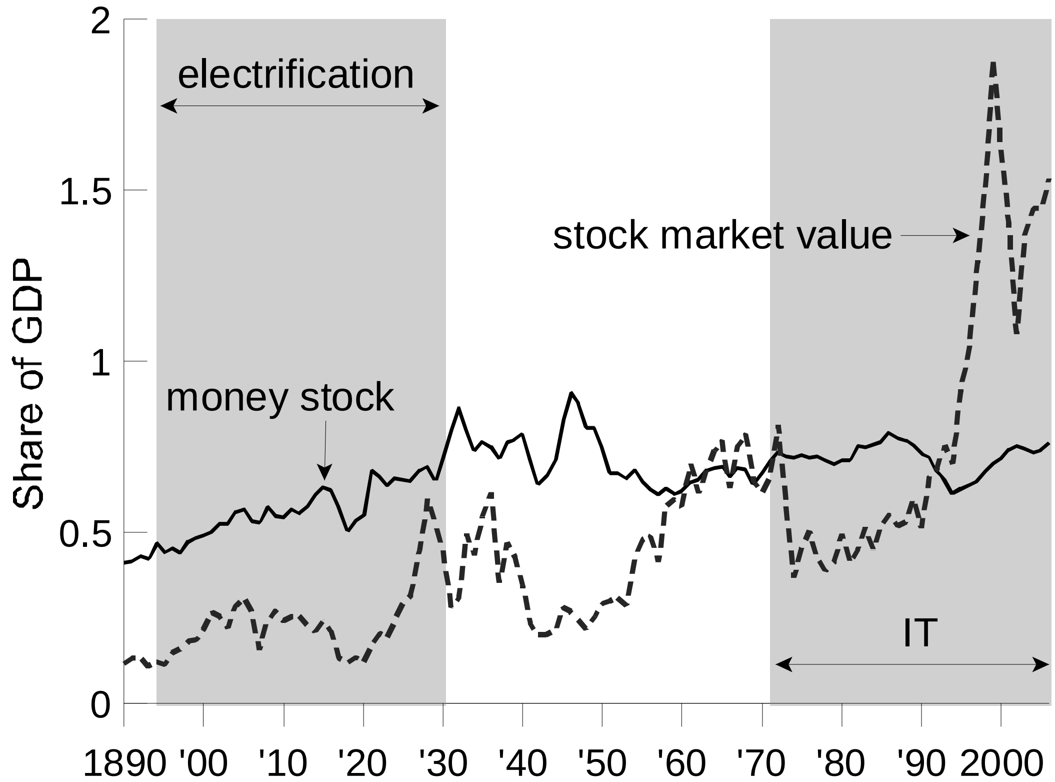

Figure 2: Broad money (M2) and stock market capitalization as shares of nominal output, 1890-2006.

2 Model: Embodied vs. disembodied technological change

We show that vintage-specific technological progress produces a rise in the age of the firm at IPO as time passes. The reason is that each new technology contains a quality improvement that the earlier vintages do not share. Arguably, vintage-specificity is important in the electricity revolution because of the importance of physical capital which, once formed to fit a particular technology (be it in the form of equipment or plant) is harder to change than human capital.

One old-economy example is assembly-line technology which could not be implemented without moving into a building especially designed to house such a technology. In this case there were advantages to waiting until the central power stations of the 1920s were ready to transmit and deliver power over a wide territory rather than building a factory around a dedicated generator. Some implementations simply needed to wait for electricity to become cheaper, making it finally cost-effective to abandon or de-emphasize sunk investments in old water and steam technologies. As

David and Wright (2003) contend, although electricity had been around for decades, the dynamo revolution did not achieve its engineering potential until the 1920s.

We shall use a tree-cutting model of the same general type as we used in Jovanovic and Rousseau (2001a), but with a multiplicative technological shock instead of the additive form that they assumed. The model is a partial equilibrium one and it takes the arrival of new ideas as exogenously given. The focus is on the timing of IPO which is taken to be the same as the time when positive cash flow can begin, roughly as in Pastor and Veronesi (2005). Philippon and Sannikov (2007) model things in a similar spirit but less extremely they allow a random cash flow before an 'upgrade' which they call an IPO.

2.1 Vintage technology

In this section the term 'vintage' refers to the date at which the firm is founded. This makes sense if the firm is founded and organized around an idea. The quality of that idea presumably depends to the general state of technology at that time. The notion is that the firm cannot substantially change its character or redefine itself after it has been founded.

As an example, consider the IPO of a pharmaceutical firm. The quality of the firm's patent – a property right to proceeds from a drug it has invented – determines the potential value of the firm. The firm's patent is issued at date τ, say, which also is roughly when the firm is founded. Thus τ is the firm's vintage, and it is the vintage of its 'technology.' The firm's inherent quality, z_τ, is thereafter fixed. The firm's value at IPO, however, depends on the investments that the firm makes in developing and testing its drug, in seeking FDA approval, and so on. The intensity of its investment is variable and subject to choice, but we shall assume that it is fixed at a constant value c. Given that c is spent each period between the firm's birth at date τ and its IPO date t, the value of the firm at its IPO will be $z_\tau f(t-\tau)$, where we assume that $f' > 0$ and that $f'' < 0$. This value is net of the cost of any capital expenditures that are made at the exact date of the IPO or later. The pharmaceutical company usually has no revenue until its drug is approved and marketed; the firm's IPO can precede this date or can come after it. We shall assume that the firm has zero revenue exactly until its IPO date.

The parameter z_τ is a vintage-specific technology parameter that is fixed over time for a firm of a given vintage. As a function of τ, z_τ increases so that later vintages are better.

The problem of a vintage-τ firm.—The firm can borrow and lend at the rate r. The firm chooses the age, T, at which to have its IPO. Its decision problem is

$$\max_T \left\{ e^{-rT} z_\tau f(T) - \int_0^T e^{-rt} c dt \right\}.$$

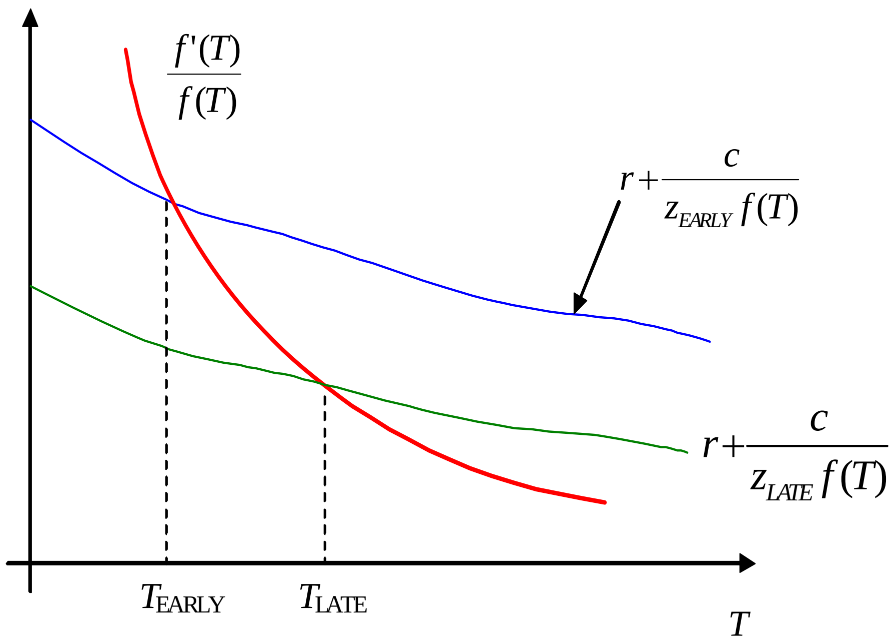

Figure 3: ILLUSTRATION OF (1)

The FOC is

$$-rzf + zf' = c.$$

Divide by zf to get[3]

$$\frac{f'}{f} = r + \frac{c}{z_\tau f}. \tag{1}$$

The LHS of (1) is the growth-rate of f and it diminishes with T. We define $T(\tau)$ to be the age at which a vintage-τ company goes public. Then the larger is z_τ, the lower will be the RHS of (1) and this means that T is higher. That is, you wait longer if you are born later. Figure 3 illustrates the LHS of eq. (1) as the steeper negatively sloping line, and the RHS as the more shallowly and negatively sloped lines for two different realizations of z. We assume that $z_{\text{EARLY}} < z_{\text{LATE}}$, and this implies that the waiting time to IPO is longer.

Example.—Let $f(t) = AT$. Then the FOC reads

$$-rzAT + zA - c = 0,$$

[3] The second-order derivative is

$$-rf'(t) + f''(t) < 0.$$

and therefore $f'' < 0$ is sufficient for the SOC to hold, but not necessary. In particular, the linear-f example that we analyze also satisfies the SOC.

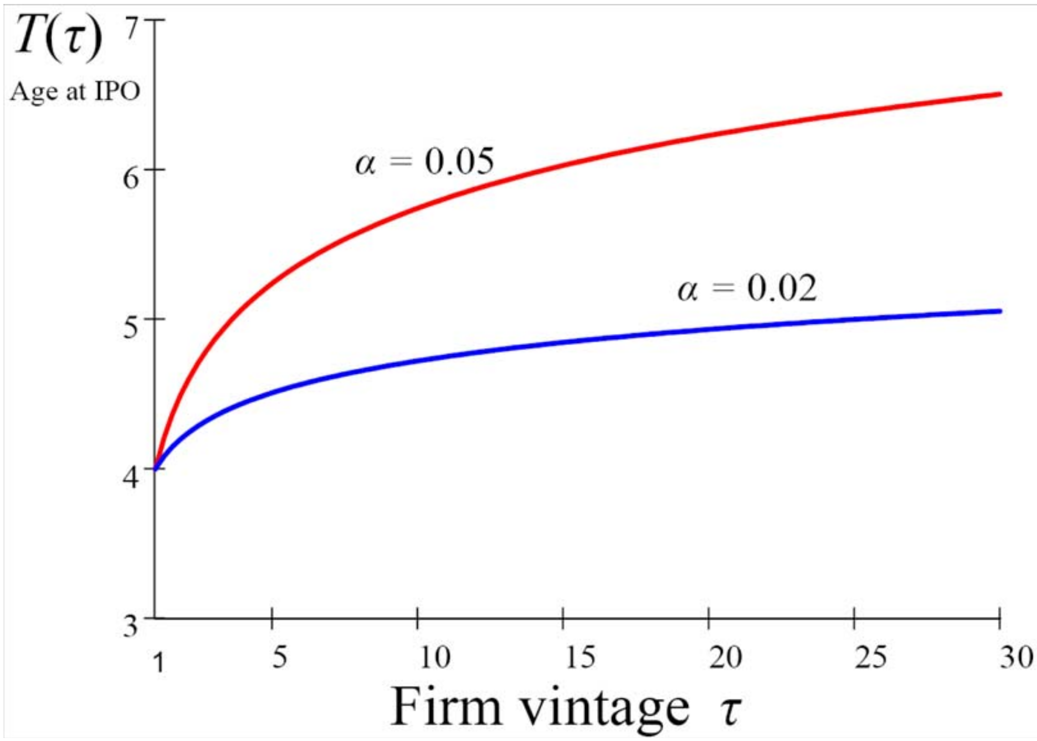

Figure 4: Embodied technological change

so that the age at which a vintage-τ company goes public is

$$T(\tau) = \frac{zA - c}{rzA} = \frac{1}{r}\left(1 - \frac{c}{z_\tau A}\right).$$

Diminishing technological progress.—We shall assume that technology improves but at a diminishing rate. Suppose that for $\tau \geq 1$,

$$z_\tau = \tau^\alpha. \tag{2}$$

If $\alpha < 1$, the technology's rate of growth diminishes with τ and technological progress eventually peters out.

Solved example.—Let $r = \alpha = 0.05$, and let $c/A = 0.8$, we have the red line in Figure 4. Lowering α to 0.02 gives us the lower, blue line. IPOs are earlier when α is smaller simply because the quality of the payoff, zf, is lower relative to the costs c of improving it further. On the other hand, the difference between the two curves is not so large. The horizontal axis in Figure 4 is the founding date of the firms, τ. To calculate the IPO date we use the formula $t = \tau + T(\tau)$. Thus if $\alpha = .05$ a firm born in year 5 will IPO in year 10, but if $\alpha = 0.02$, it will IPO in year 9.

2.2 Disembodied technology

Vintage capital instead of vintage technology.—Section 2.1 assumed that z_τ is determined at the date when the firm is born, and not at the time of its IPO when a large influx of capital usually occurs. If the latter assumption is made instead[4] then the nature of the IPO decision changes and becomes similar in character to the case where technological change is completely disembodied. In both cases there is an incentive to delay the IPO so as to gain a higher z. Therefore we shall therefore treat both these cases together as 'disembodied' technological change. Firms do not embody the technologies that were state of the art when they were founded.

Suppose then that a firm of age T that IPOs at date t will receive an IPO valuation of $z_t f(T)$. The difference now is that z_t keeps growing as the firm waits, whereas in the previous case it was fixed at z_τ, unaffected by the passage of time.

The IPO decision at date t.—In order that a firm be willing to have its IPO at date t, the maximum of the problem

$$\max_T \left\{ e^{-rT} z_{\tau+T} f(T) - \int_0^T e^{-rt} c dt. \right\}$$

must satisfy the FOC

$$-rzf + zf' + z'f = c. \tag{3}$$

If the LHS of (3) exceeded the RHS, the firm would wish to wait longer to have its IPO. at date t, at which point $z = z_t$. Divide again by zf to get

$$\frac{f'}{f} = r - \frac{z'}{z} + \frac{c}{zf}. \tag{4}$$

Comparing (4) to the earlier FOC (1), we see a new term, $-z'/z$ on the RHS. This is the effect that waiting has on the improvement of the exogenous technological parameter. The term is present in the Jorgenson user cost of capital expression – the user cost is higher when the price of capital declines more rapidly. In (4), the first two terms on the RHS work in opposite directions. The term $\frac{c}{zf}$ declines with time because z and f both grow. But the term z'/z is the growth of z and if technological progress spends itself, the term $-z'/z$ rises and this force induces firms to start IPO-ing younger.

The example revisited.—Let us return to the same example as before, with the sole change being that z is now a disembodied rather than an embodied technological change parameter, so that instead of (2), we have

$$z_t = t^\alpha,$$

where t is calendar time. Now the FOC reads

$$-rzAT + zA + z'AT = c,$$

[4] As in Jovanovic and Lach (1989), for example.

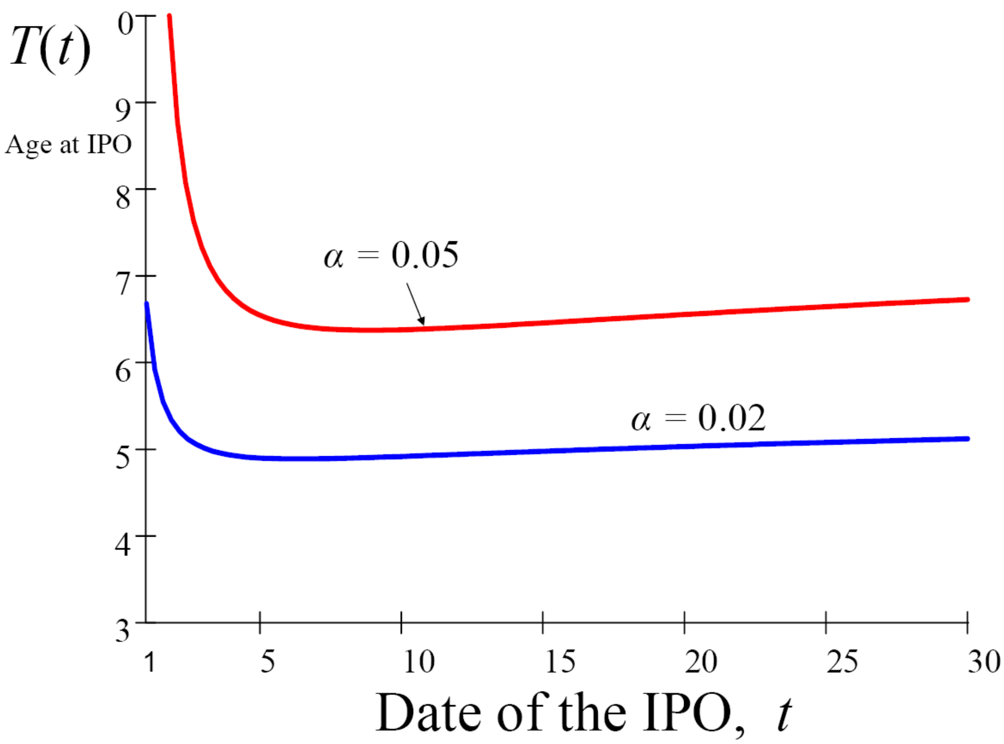

Figure 5: Disembodied technological change

so that

$$T = \frac{zA - c}{rzA - z'A} = \frac{1}{r - \frac{z'}{z}} \left(1 - \frac{c}{zA}\right).$$

Note that $z'/z = \alpha/t$ so that the incentive to wait for technology to improve diminishes arithmetically in t. Thus $T(t)$ is initially decreasing and continues to fall until it reaches a global minimum. With the same parameter values as before and $\alpha = 0.05$ we have the red line in Figure 5. When we drop α to 0.02, we get the blue line.

In contrast to Figure 4, the horizontal axis in Figure 5 measures calendar time. The vintage of these firms is therefore $t - T(t)$. For low t, firms IPO at relatively high age; that is, $T(t)$ is high. The intuition is this: Since z grows rapidly for small t, these firms will delay no further only if their internal growth opportunities f'/f have been more or less exhausted. But the latter is only true for high values of T. Therefore any firm IPO-ing when t is low must have a high T.

Comparing Figures 4 and 5, we see that T is of the same order of magnitude in the two sets of cases. In the embodied case described in Figure 4, over the 30-year period the mean of T is 4.6 years when $\alpha = 0.02$ and 5.8 years when $\alpha = 0.05$. In the disembodied case described in Figure 5, over the 30-year period the mean of T is 5.2 years when $\alpha = 0.02$ and (restricted to $t \geq 2$) 6.8 years when $\alpha = 0.05$. Thus the levels of T in the two figures are comparable, but the slopes differ. Since all parameters are the same except for the interpretation of z, the difference is coming entirely from the additional incentive (in the disembodied case) to wait for further technological progress to augment the value of the firm. The incentive to delay weakens as t grows and the prospect for further improvement diminishes.

3 Vintage-specific capital endowments

A different type of explanation invokes not technology endowments but, rather, capital endowments. Let us imagine that in order to have an IPO the firm must jump over a hurdle. Suppose that the hurdle is a certain level of capital – it does not matter whether it be physical or human. Then a firm that has more capital to begin with will be able to jump over the hurdle sooner. That is, such a firm will be younger when it has its IPO.

This is precisely what happens in the model of Greenwood and Jovanovic (1990, 'GJ'). In GJ firms live forever and so it is difficult to talk about age but let us ignore this detail for the moment. The useful thing in GJ for our purposes is that there are two stages in a firm's life – pre and post IPO. But the behavior of GJ could probably be replicated in many other models if firm lifetimes were to be broken up into two such stages.

The only thing in GJ that differentiates firms is their assets or 'capital', k. Firms switch regimes and join the financial sector when their capital reaches a critical level, call it k^*, at which it becomes worth it to pay a fixed cost and 'join the financial sector', which we shall call an IPO. Introducing random death does not change these implications. Thus we would write the time-to-wait to IPO as a function $T(k)$ which is positive for $k < k^*$, decreasing in k and becoming zero for $k \geq k^*$, as drawn in Figure 6. The function $T(k)$ tells us how many periods it will take for the firm to reach k^* starting from k. The closer it is to k^*, the less it has to wait for its IPO. A generation born with $k > k^*$ would IPO at once!

Introducing generation-specific variation in the capital endowment at birth would imply younger ages at IPO for those generations that started life with a lot of capital. An IPO wave would then occur if for some happy reason several generations were bunched together with a high starting value of k. Thus if we let k_τ denote the initial capital level of the vintage-τ generation, in an epoch during which k_τ was decreasing in τ, IPO age would be increasing over the periods when those generations would experience their IPOs. It is possible, therefore, that the 1920s and, more generally, the first half of the century were such a manifestation. For the second half of the century we would need the opposite: k_τ would need to have been increasing in τ. It would, of course, be nice to have measures of k_τ, i.e., the initial (human?) capital levels of the various generations of firms.

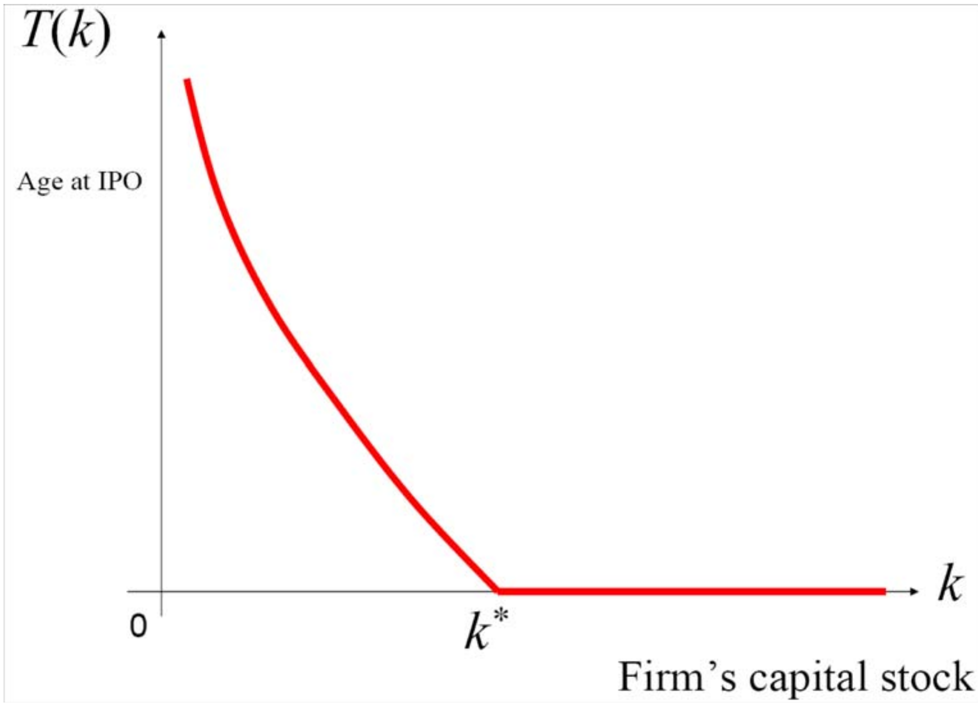

Figure 6: IPOs in GJ's model

4 Discussion

How do we show that there exist such things as vintage-specific technology or capital endowments? Until some evidence on these points materializes to infuse discipline on our various explanations for the 20s' IPOs, they must remain speculative. Let us now discuss the possible bearing of some other papers on the questions at hand. This discussion will be suggestive since the models do not break up firms' lives into two stages.

Plehn-Dujowich (2007) assumes that an infinite succession of products is produced by a fixed set of agents over time. The ablest agents have a comparative advantage in making new products. They are the first to exit old or dying industries and to enter new industries. It is a theory of lateral entry and does not unambiguously suggest that the best firms are the first to have their IPO. But if one were to assume that all firms are of the same age and that a firm's IPO date is the date when the firm enters a new industry, then the model explain why the age of IPOing firms rises. In contrast, in our vintage model, the early IPOs are less efficient than later ones.

Helpman and Trajtenberg (1994) assume that major breakthroughs that they call general-purpose technologies or GPTs occur exogenously at discrete points in time. The shaded areas in Figure 1 are two such epochs, argue Jovanovic and Rousseau (2005). The use of a GPT requires that a certain number of complementary inputs be developed. After sufficiently many such inputs exist, manufacturers of final goods abruptly switch from the old technology to the new GPT. When that switch occurs, the makers of the inputs specific to that GPT start to make profits. At this point the previously-invented intermediate products have been gestating in a way similar to a private firm waiting to IPO. In contrast to the model we presented, the intermediate inputs are all the same – there is not variation among them in what we would call z. The early intermediate-goods developers remain without revenue for a certain period of time, whereas the later developers are profitable right away, but have shorter lifetime.

The industry-level vintage-capital models of Jovanovic and Lach (1989), Mitchell (2002), Aizcorbe and Kortum (2005), and Jovanovic and Tse (2007) are also relevant because firms of different vintages have different quality levels. These models all involve free entry and this feature causes equilibrium industry price to decline at the same rate as the technological progress. The correspondence between technological progress and product-price declines is exact in all these models except in Jovanovic and Lach, which has transitional dynamics.

5 Conclusion

The question we posed was 'Why does the age of IPO-ing firms rise in the 20s and more generally in the first half of the Twentieth Century?" We contrasted this to the declining IPO age during the second half of the century. We explored several hypotheses that would account for both sets of phenomena and showed that they match somewhat the IPO age data. But one needs more evidence before speculation can become explanation.

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