

Interest rates and the timing of new production

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Introduction and summary

Policymakers are naturally interested in the effects of interest rates on various economic activities. This article studies how interest rates affect entrepreneurs' propensities to initiate new projects. Since the implementation of new ideas and production techniques is an important engine driving long-run economic growth, the effect of real rates on this activity should be of particular interest. This article illustrates that the effect of interest rates on the incentives to implement is not monotonic. Starting at high interest rates, a fall in the interest rate will spur entrepreneurs to implement projects more rapidly. But lowering interest rates even further will only persuade entrepreneurs to delay.

Ordinarily it would be difficult to measure the extent of delay, since we cannot easily identify when an economic agent first received the opportunity to bring a project to fruition. To get around this, we look at initial public offerings (IPOs). Although the decision to issue an IPO may reflect a host of considerations, Jain and Kini (1994) find that IPOs appear to be related to growth in investment and sales. More importantly, we can measure the amount of time that transpired between when a firm was founded or incorporated and when its IPO was issued, so we have a reasonable proxy for the delay time. Data on the time it takes firms to go public show a non-monotonic correlation between interest rates and the age at which the firm goes public. High rates of interest induce a delay and discourage investment for the usual reason, namely that when future income is discounted more heavily, it is not worthwhile to sacrifice current resources. Very low rates of interest, however, also discourage investment, because profits that are foregone during the delay are not as costly in comparison with the gains to delaying.

Chetty (2001) has shown that irreversibility of investment can lead to a non-monotonic relation between

interest rates and investment. In his two-period model, if investment is postponed to the second period, the firm can better react to news about demand conditions. Aside from offering a different model, we also provide evidence on the non-monotonicity. In earlier work, Jovanovic and Rousseau (2001) show that the incentive to delay implementing a project gets stronger as the interest rate falls. In that paper, we also provide an information-theoretic rationale for the gains to waiting, but do not give any evidence.

The non-monotonicity of physical investment in the interest rate stems, ultimately, from the fact that the firm is giving up profits while it waits to implement its project. The decision to wait itself delivers information, that is, human capital, hence what is really happening is a substitution of one form of capital for another. We comment on this again in the conclusion and the implications that it may have for countries like Japan that are experiencing low investment, in spite of enjoying very low interest rates.

In the next section, we explain the model, and in the following section we describe its main implications for the data that we have. Then, we test those implications and discuss some related literature.

The model

The following model is a simplified version of Jovanovic and Rousseau (2001). Suppose the firm lives forever and has the property rights to its project. When implemented, the project produces output using

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knowledge and physical capital k . The firm starts to receive net revenue cash only after it implements the project. Let T denote the waiting time until implementation. Suppose that while it waits, the firm's potential output is

$$y = f(T).$$

We assume that f increases with T but at a diminishing rate, as drawn in figure 1. In this formulation the firm starts receiving y only *after* implementing the project. At that point the project starts yielding profits. Moreover there are no direct costs. In that case the implementation decision is much like the decision of how long to remain in school. This is like perfecting an idea before taking out a patent on it.

Choosing the implementation date when there is no physical capital

If the firm lives forever and has the property rights to its project, it must just decide when to implement it. There are no direct costs. Only implicit “foregone-earnings” costs. The problem we analyze is similar to the well-known tree-cutting problem in economics, in which one wants to figure out the optimal time to cut down a tree. The trade-off involved is that between selling a young tree for cash today as opposed to selling a more mature tree for more cash tomorrow. The rate of interest has an important influence on that trade-off.

Formally, the firm's problem is that of choosing the implementation date T to maximize the present value of its future net revenues

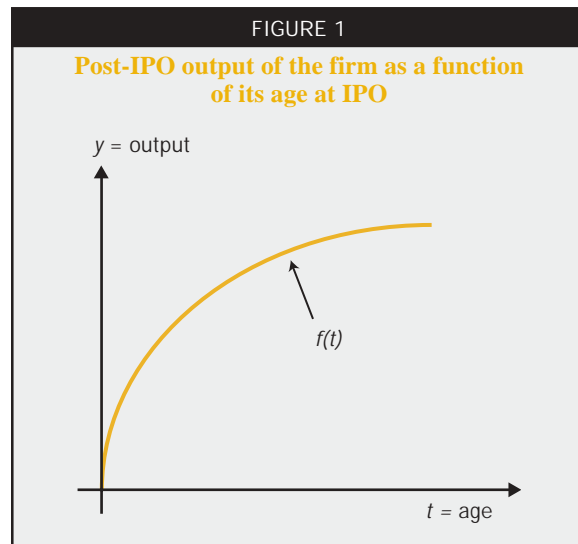
$$e^{-rT} \frac{1}{r} f(T).$$

One can show that the optimal timing will satisfy the following equation:

$$1) \quad f(T) = \frac{1}{r} f'(T).$$

The left-hand side of equation 1 is the foregone-earnings costs of waiting another period. In the problem as stated, this is the only cost. The right-hand side is the gain from waiting. Since this gain is received in every subsequent (production) period, it is capitalized, and hence the r in the denominator. It is more revealing to write the condition as

$$2) \quad g = r,$$



where

$$g \equiv \frac{f'(T)}{f(T)}$$

is the rate of growth of potential output. Thus, the implementation occurs when g equals the rate of interest.

Example

As an example, consider $f(t) = At^\alpha$, where $\alpha < 1$.

Here the condition reads $\frac{\alpha}{T} = r$, so that

$$3) \quad T = \frac{\alpha}{r}.$$

In this simple version of the model, then, a rise in the rate of interest hastens the implementation because it makes the foregone-earnings cost of waiting more important relative to the future gains from waiting. Interestingly, the productivity of the firm, A , does not affect the firm's implementation date because it simply scales both costs and revenues in the same proportion.

The parameter α will be important in what follows. It measures the gain in productivity that the firm gets by delaying its implementation. Delay lets the firm resolve technological uncertainties, perfect its ideas, and choose the right inputs for its production process.

Adding physical capital

To the extent that implementation entails spending on capital goods (as suggested by the evidence in Jain and Kini, 1994), this implies that the effect of the real rate of interest on investment is unambiguously

positive! Lower rates discourage implementation by inducing firms to wait longer so as to perfect their investments. The only cost is that of the profits that are postponed—a foregone-earnings cost.

In reality, firms must incur direct costs of implementation. However, these direct costs now introduce a new consideration: Higher interest rates imply it is better to defer these costs into the future since their present value is smaller. This suggests that lowering the interest rate will mitigate the incentive to delay, and that ignoring fixed costs of implementation (even if they do not correspond to measured investment) may be misleading. Therefore, we now introduce capital expenditure of I that is incurred at the implementation date. This modifies the firm's problem to one of choosing T to maximize the following present value:

$$e^{-rT} \left\{ -I + \frac{1}{r} f(T) \right\}.$$

One can now show that the optimal timing will satisfy the following equation:

$$4) \quad rI - f(T) + \frac{1}{r} f'(T) = 0,$$

so that instead of equation 2, the condition of optimality reads

$$5) \quad g = r - \left(\frac{I}{f(T)} \right) r^2.$$

Now g is essentially a quadratic in r . When r is small, the effect of r on g is positive as before, but when r gets large, the opposite is true, and the effect of r on g is non-monotonic. Note, too, that the coefficient on r^2 is the capital output ratio. As a result, the effect on T is non-monotonic too, and with it the effect on implementation investment.

The example again

To illustrate this, let us return to and augment the example $f(t) = At^\alpha$ we outlined above. The firm's problem becomes one of choosing T to maximize the following present value:

$$e^{-rT} \left\{ -I + \frac{1}{r} AT^\alpha \right\}.$$

Figure 2 plots the optimal implementation delay on the vertical axis and the rate of interest on the horizontal axis. We see that for a smaller r , the term $2/r$ dominates, driving T to infinity. For a larger r , the term rI/A dominates, again driving T to infinity. We therefore have a U-shaped relation between r on the horizontal axis and T on the vertical, as illustrated in figure 2 for the case where $I = 30A$. We also plot T for the case where $I = 45A$, and $I = 60A$. We note that 1) the curves bottom out at levels of r ranging between 5 percent and 10 percent, and 2) higher investment outlays imply longer waiting at all levels of the interest rate. For practical purposes, however, the size of the outlay, I , starts to matter only when the interest rate is relatively high, say above 4 percent.

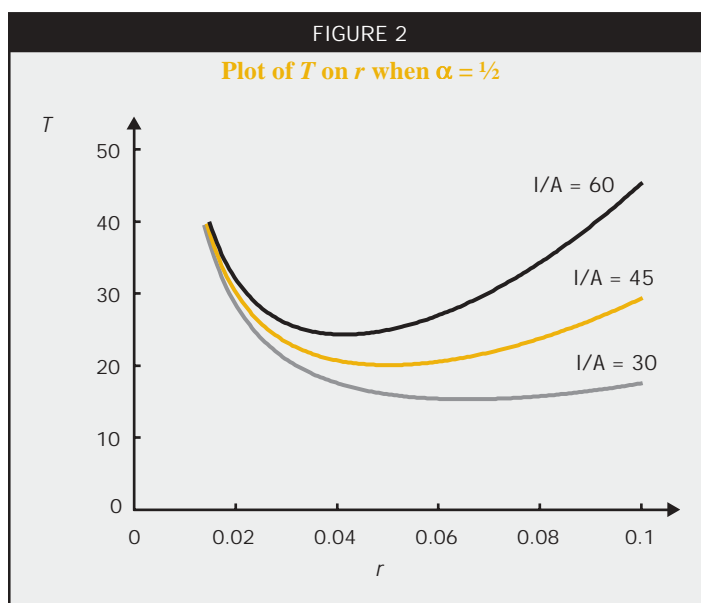
Implications of the model

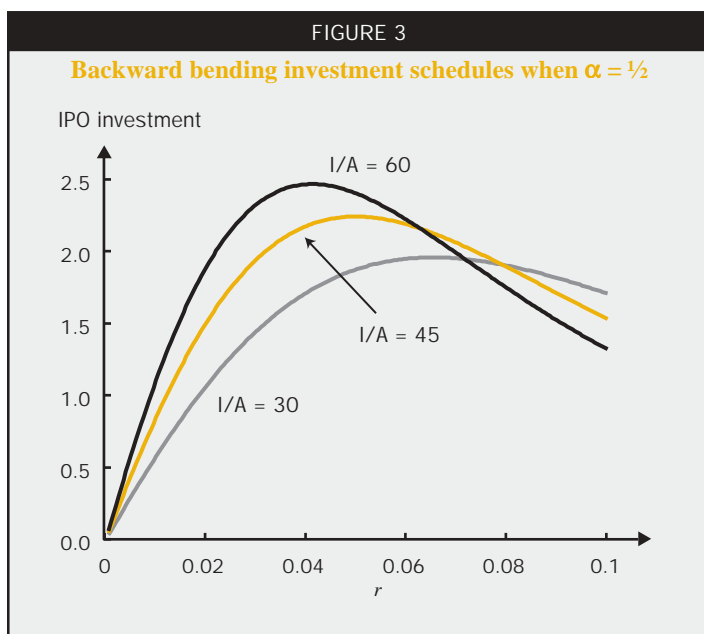
The model has time-series and cross-sectional implications. The time-series implications concern low-frequency movements in T and the market value of the firm at IPO, which we denote as

$$v = e^{-rT} \left\{ -I + \frac{1}{r} AT^\alpha \right\}.$$

We are especially interested

in the relation between interest rates and IPO investment. The model assumes that r is fixed, and therefore we may, at best, take figure 2 to predict the effects on T of low-frequency movements in r . These movements will induce changes in total investment spending—the total outlays on I —that we associate with implementation investment. The above framework lets us derive the following results.





Relationship between time to go public and the real interest rate

At low frequencies, the relation between T and r is U-shaped, as figure 2 shows. This means that the investment schedule is backward bending. We note that the negative relationship that emerges at low levels of the real rate is more pronounced than the positive relation at higher rates and that such high rates are not often observed.

Relationship between investment and the real interest rate

The results on the effects of r on T can now be translated into results for IPO investment. A rise in T means that investment is postponed. Consider the stock of new projects that need implementing. Into this stock there is an inflow of new projects as entrepreneurs get new ideas and at the same time an outflow due to projects being implemented. Investment will be proportional to the outflow of projects, because any project that is implemented requires investment. An increase in T will imply that the current cohort of projects will take a long time to leave. But if the inflow of ideas is constant, in the new steady state the outflow will be constant as well. Any effects of changes in T will only affect the transitional path.

The size of this transient effect will depend on the difference $T_{NEW} - T_{OLD}$.

To see this more clearly, consider an economy that has a constant inflow of ideas. If a change in r (perceived by firms to be permanent) raises T , then strictly speaking we should see no investment at all for $T_{NEW} - T_{OLD}$ periods, followed immediately by the same steady state investment rate as took place before the change. Conversely, if a change in r lowers T , then there would immediately be a burst of investment that implements all existing ideas that are older than T_{NEW} . The general point is that interest-rate variation at low frequencies will produce changes in investment that are in the direction opposite to the change in T , and this change is related to the level of T_{NEW} .

Roughly speaking, then, decade to decade, we may expect a negative relation between T and implementation investment. Therefore, the relation between investment on the vertical axis and the rate

of interest on the horizontal should have an inverted-U shape. We illustrate this in figure 3. The vertical axis shows the ratio I/T plotted against r by decade. The curves cross because T is increasing in I , and the ratios are not ordered the same way at different levels of r . But what is important here is the inverted-U shape in the graph and this is what we are looking for in the data.

IPO-issuing firms versus stock-market incumbents

Our model derives implementation lags from the improvement of projects prior to their implementation.

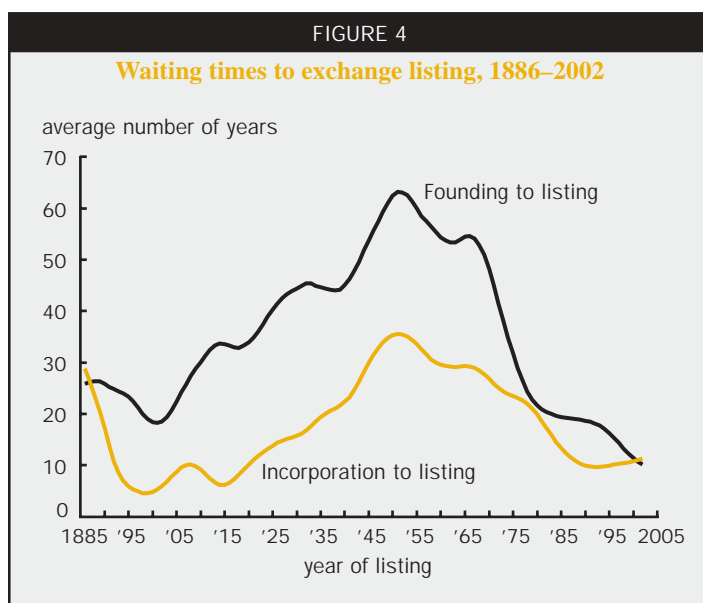


TABLE 1

Firms in the waiting-time sample

Decade	Number of new CRSP listings	Number of incorporations	Number of foundings
1890–99	112	52	41
1900–09	112	78	44
1910–19	214	190	97
1920–29	545	492	273
1930–39	231	197	78
1940–49	271	246	97
1950–59	254	241	78
1960–69	2,008	964	198
1970–79	4,517	1,405	262
1980–89	6,322	904	790
1990–99	7,850	1,539	1,939
2000–02	1,311	324	324
Total	23,747	6,632	4,221

It is the upward slope in figure 1 that creates the incentive for a firm to delay implementation while the project is improved and refined. The returns to waiting should, in turn, depend on how uncertain the environment is for the firm and its project. These uncertainties are likely to be greater for new products and new markets, and it is in such products and markets that new firms predominate. IPO-issuing firms tend to be new, or they at least tend to be younger than most established corporations. Therefore, we expect to see a difference between the investment behavior of entrants and incumbents.

The parameter that the model isolates in this regard is α . The curvature of f is likely to be larger, and the returns to waiting likely to be smaller, for established firms. This is most evident in equation 3, where a low α reduces the incentive to delay and therefore mitigates the forces that we have been describing here. In the expanded version of the model where we allow for physical investment, this simply means that the incentive to delay because of improving the project is weaker relative to the standard considerations of comparing I with discounted profits.

As a result, we expect to find a quantitative difference between the estimated investment schedules of incumbents and IPO-issuing firms. Even for incumbents, the incentives to delay should be there, but they should be much smaller. We thus expect to see less of a backward

bend, if any, in the investment schedules of established firms.

Tests of the implications

Having listed the main implications of the model, we report on how they fare with the data, taking them up in the same order as above. IPOs provide a context for measuring a delay until investment—Jain and Kini (1994) find that IPOs are associated with a rise in investment and sales. Our use of IPO data in testing the theory is reasonable if:

1. Funds are a constraint for private companies;
2. IPOs can deliver the funds for a significant expansion; and
3. Upon the initial expansion, the firm is irrevocably defined and its IPO investments cannot be reversed.

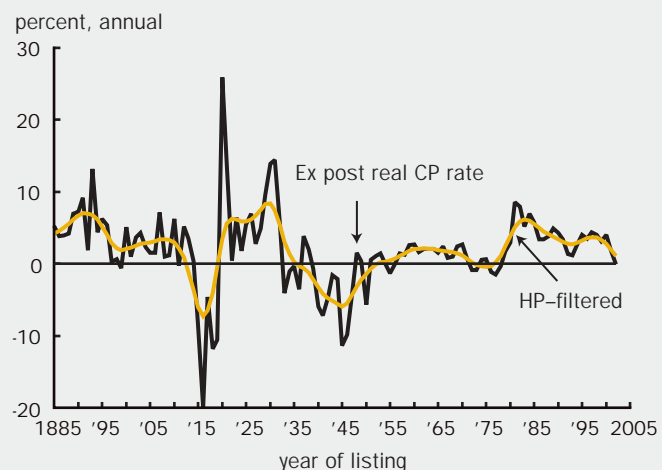
When these assumptions hold at least approximately, we may interpret the firm's age at the IPO date as a proxy for the delay time to investment. Some of the costs incurred at IPO are transaction costs—Lee et al. (1996). We lump all costs into I and treat them as “investment.”¹

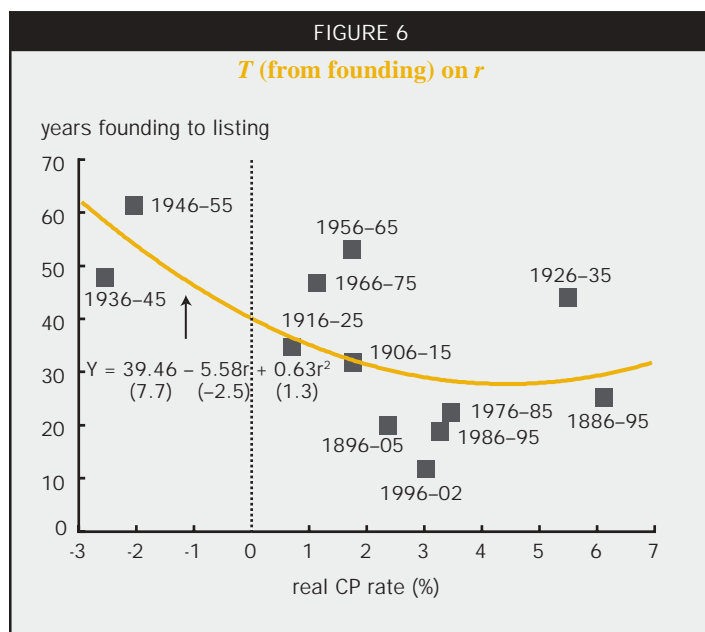
Testing the relationship between time to go public and the real interest rate

The first implication says that the relation between T and r should be U-shaped. To measure T , we construct average waiting times from founding and incorporation to stock-exchange listing since 1886,

FIGURE 5

The ex post real interest rate on commercial paper, 1885–2002





based on individual company histories and our extension of the stock files distributed by the University of Chicago's Center for Research in Securities Prices (CRSP) from its 1925 starting date back through 1885 using newspaper sources.² Figure 4 shows these series after smoothing with the Hodrick-Prescott filter. Table 1 shows the coverage of our collection of IPO waiting times by decade. Waiting times by either measure were longest in the 1950s and 1960s and shortest at both ends of the twentieth century.

To what extent do these waiting times reflect waiting to implement projects? According to figure 4, the smoothed number of years between founding and listing ranges from ten to 60 years. It is hard to believe that a firm delays entirely for the purpose of perfecting and honing and then finally initiating its project when it goes public. Moreover, many profitable firms remain private. The time it takes to go public probably depends on several factors that are absent from our model. What matters, however, is time variation in the time to go public, which, barring any technological changes, is probably driven partly by incentives that we have modeled. While it may at first seem unlikely that the age at IPO should have increased by 15 years or 20 years in the 1940s entirely in response to interest rates, figure 2 shows that the model is able to generate very sharp increases in waiting times as interest rates

near zero. Indeed, this is a robust implication. From equation 5 it follows that as the interest rate tends toward zero, the waiting time goes to infinity. No other parameter restrictions are required for this conclusion to hold. It is also true, however, that the relation is much steeper at low rates than it is at high rates. Thus, the greatest potential of this model to explain waiting times is when interest rates fluctuate around a low level.

Figure 5 shows the real interest rate on commercial paper with 30–90 days until maturity from 1885 to 2002, along with an HP-filtered (Hodrick–Prescott) trend.³ Real rates were lowest in the middle of the twentieth century, and the series is roughly U-shaped. The long wait times in the 1950s and the corresponding negative real interest rates appear roughly consistent with our model. To examine the low-frequency

relationship between T and r more precisely, however, we average both across ten-year periods and test for non-monotonicity with a quadratic regression.

Figure 6 shows a scatterplot of averages by decade of T on r , with T measured by the number of years from founding to exchange listing. Figure 7 instead uses years from incorporation as the measure of T . In either case, a U-shaped pattern appears in the data. The regressions in table 2 confirm this, with the coefficient on the real interest rate negative and significant at the 5 percent level for the linear term and positive (though

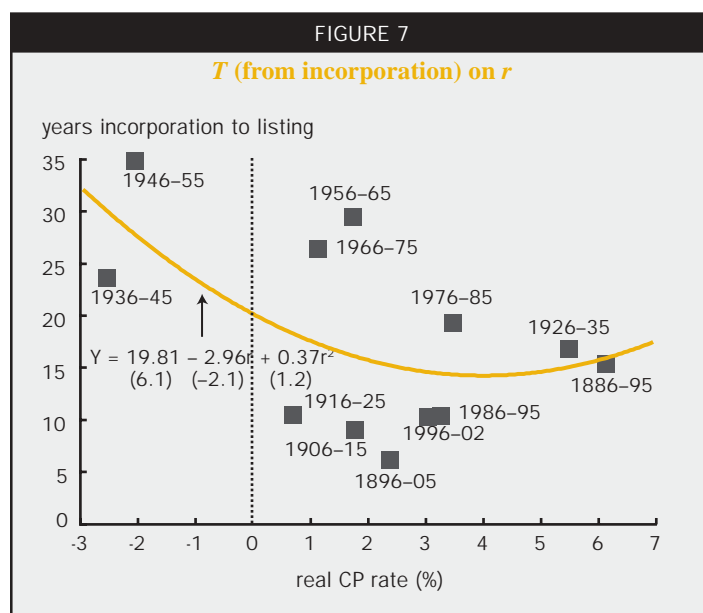


TABLE 2

Regressions of waiting times (T) on the real commercial paper rate (r) by decade, 1886–2002

	Dependent variable			
	T from founding		T from incorporation	
r_t	-3.47 (-2.23)	-5.58 (-2.46)	-1.71 (-1.77)	-2.96 (-2.07)
r_t^2		0.63 (1.25)		0.37 (1.17)
constant	41.68 (8.37)	39.46 (7.65)	21.11 (6.80)	19.81 (6.10)
R^2	.33	.43	.24	.34
N	12	12	12	12

Note: T-statistics are in parentheses.

not significant) for the quadratic term. We interpret this as supporting evidence for the first implication of our model. We note, however, that negative real interest rates are inconsistent with the model and that instead of varying between 0 percent and 10 percent (as the interest rate does in the theoretical plots of figures 1–3), the decade averages vary from about -3 percent to 7 percent.

Testing the relation between investment and the real interest rate

The second implication deals with the relation between IPO investment and the real rate of interest. In testing for this, we provide a parallel analysis of the relation between aggregate investment (which is dominated by investment of stock-market incumbents) and the rate of interest. We do this to contrast the two relationships.

IPO-issuing firms probably face much greater uncertainty than incumbent firms. IPO-issuing firms are in the process of defining themselves, their products, and their technologies, and once they have chosen these directions, there is no going back for most of them. Choosing the wrong standard, for example, can condemn a new business to an early demise. There is a real sense, then, in which their investments are irreversible.

Incumbent firms, on the other hand, have chosen their domains of operation and face uncertainty more in the scale of demand, input prices, and so on. For these firms, there is less to be gained by waiting

because there is less uncertainty to be resolved by delaying investment. Therefore, we would expect the investment of incumbents to be negatively related to the rate of interest. So, while we do not offer a model of incumbent investment, we note that the standard Q-theory model of investment (for example, Hayashi, 1982) with convex adjustment costs and no irreversibilities, predicts that a rise in the interest rate reduces investment.

Our model implies that, unlike incumbent investment, the relation between IPO investment and the rate of interest should be an inverted-U. Figure 8 shows the two investment series that we consider. The yellow line is private domestic investment as a percentage of the aggregate capital stock.⁴ The black line is the value of IPO-

issuing firms at the end of each year as a percentage of total stock market capitalization.⁵ While investment rates tended to rise until the Great Depression and then stabilized after World War II, IPOs followed a more erratic pattern, with the value of new equity largest around the turn of the twentieth century, around 1915, in the late 1920s, at the end of World War II, in the late 1960s, the mid-1980s, and the 1990s.

To examine the low-frequency relationship between these measures of investment and r more precisely, we again average across ten-year periods.

Figure 9 shows a scatterplot of decade averages of r on IPO value, along with the fitted values from a quadratic regression. Figure 10 shows the scatterplot and quadratic regression line for incumbents' investments.

FIGURE 8

**Annual IPOs as a % of stock market value;
private investment as a % of the capital stock, 1886–2002**

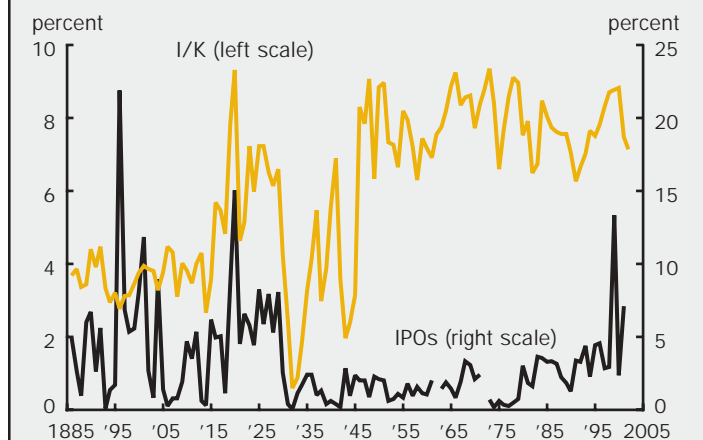


FIGURE 9

IPOs as a share of stock market capitalization

The figure is a scatter plot with a quadratic regression line. The vertical axis is labeled 'IPOs/stock market (percent)' and ranges from 0 to 8. The horizontal axis is labeled 'real CP rate (%)' and ranges from -3 to 7. A vertical dotted line is drawn at x = 0. The regression equation is
$$\text{IPO/Mcap} = 3.51 + 5.56r + 0.11r^2$$
 with coefficients (4.7), (1.7), and (-1.5) respectively. An arrow points from the equation to the vertical dotted line. Data points are labeled with time periods: 1936-45, 1946-55, 1956-65, 1966-75, 1976-85, 1986-95, 1996-02, 1886-95, 1926-35, 1896-05, and 1916-25.

Time Period	real CP rate (%)	IPOs/stock market (percent)
1936-45	-2.5	1.4
1946-55	-2.0	1.6
1956-65	1.5	2.5
1966-75	1.0	3.8
1976-85	3.5	2.0
1986-95	3.0	3.0
1996-02	2.5	5.5
1886-95	6.0	3.4
1926-35	5.5	3.8
1896-05	2.0	7.5
1916-25	0.5	6.5

We have assumed that, at IPO, the public pays exactly what the firm is worth.

The broader implication of our work here is that lowering interest rates may impede new ideas rather than foster them. But this does not mean that low interest rates are bad for firms, even when they lead firms to postpone their investment. Regardless of

FIGURE 10

Investment rate on r

I/K

9
8
7
6
5
4
3
2

-3 -2 -1 0 1 2 3 4 5 6 7

real CP rate (%)

1966-75
1996-02
1976-85
1956-65
1986-95
1946-55
1916-25
1936-45
1906-15
1896-05
1926-35
1886-95

$I/K = 6.76 + 0.21r - 0.11r^2$
(8.5) (0.6) (-0.5)

TABLE 3

**Regressions of IPOs and the investment rate
on the commercial paper rate (r) by decade, 1886–2002**

	Dependent variable			
	IPOs / Stock market		I/K	
r_t	0.20 (0.86)	0.56 (1.71)	−0.16 (−0.66)	0.21 (0.61)
r_t^2		−0.11 (−1.48)		−0.11 (−1.45)
constant	3.13 (4.23)	3.51 (4.71)	6.37 (8.08)	6.76 (8.49)
R^2	.07	.25	.04	.22
N	12	12	12	12

Note: T-statistics are in parentheses.

how investment reacts, the value of projects rises as the interest rate falls.

Nor do our results say that low interest rates discourage all investment broadly defined. Our finding that at low rates *physical*-capital investment rises

with the interest rate is really about the composition of capital. A delay is a switch of one kind of investment profile for another. When the reason for delaying is the gathering of information, total investment (including information investment) may still be monotone-decreasing in the interest rate. Firms postpone physical investment, but they gather information, and this is human capital. Before implementing its project, the value of that project is monotone-decreasing in the interest rate, and that value—that is, the value of the physical and human capital combined—is being maximized by the firm's policy. Thus, when physical investment rises with the interest rate, this simply means that the firm's human capital investment is falling, and perhaps its total capital

properly measured. Therefore, for example, the Japanese economy may be in better shape than it seems today because the very individuals that are not investing may be accumulating a different kind of capital that is not measured as such.

NOTES

¹Other evidence shows that increasing funds for investment is indeed one of the motives behind an IPO. Jain and Kini (1994, table 2), for example, find that by the fourth year after its IPO, the firm will experience a rise in sales of 80 percent compared with its industry counterparts and 143 percent compared with its own sales in the year just before the IPO (also see Choe, Masulis, and Nanda, 1993; Lowry, 2002; and Moskowitz and Vissing-Jorgensen, 2002). We find that the 1955–2001 correlation between funds that firms take in at IPO and their real investment is 0.33 and highly significant.

Our assumption that the firm's investment occurs at the time of IPO brings us closer to the literature on liquidity constraints. When an entrepreneur has a high return activity that he cannot fund in the capital market, he has a greater incentive to save, because those savings can fund an investment that is more profitable than the average market investment. Buera (2003) analyzes optimal saving behavior by liquidity-constrained entrepreneurs.

²Listing years after 1925 are those for which firms enter CRSP. For 1885–1924, they are years in which prices first appear in the New York Stock Exchange (NYSE) listings of *The Annalist*, *Bradstreet's*, *The Commercial and Financial Chronicle*, or *The New York Times*. The 6,632 incorporation dates used to construct figure 4 are from *Moody's Industrial Manual* (1920, 1928, 1955, 1980), *Standard and Poor's Stock Market Encyclopedia* (1981, 1988, 2000), various editions of *Standard and Poor's Stock Reports*, and *Mergent Online*. The 4,221 foundings are from Dun and Bradstreet's *Million Dollar Directory* (2000), *Moody's*, Etna M. Kelley (1954), and individual company websites. We linearly interpolate the series between missing points before applying the HP-filter to create the time series in the figure.

³Commercial paper rates are annual averages of 30-day terms from the FRED (Federal Reserve Economic Data) database for 1934–2002 and 60–90 day terms from Homer and Sylla (1991) for earlier years. We compute the ex post return by subtracting inflation as computed by the growth of the implicit price deflator for gross domestic product (GDP) from the U.S. Bureau of Economic Analysis (BEA) (2003) for 1929–2002 and Berry (1988) for earlier years.

⁴To build the investment rate series, we start with gross private domestic investment in current dollars from the U.S. Bureau of Economic Analysis (2003, table 1, pp. 123–124) for 1929–2001 and then ratio-splice the gross capital formation series in current dollars, excluding military expenditures, from Kuznets (1961b, tables T-8 and T-8a) for 1870–1929. We construct the net capital stock using the private fixed assets tables of the Bureau of Economic Analysis (2003) for 1925–2002. Then, using the estimates of the net stock of non-military capital from Kuznets (1961a, table 3, pp. 64–65) in 1869, 1879, 1889, 1909, 1919, and 1929 as benchmarks, we use the percent changes in a synthetic series for the capital stock formed by starting with the 1869 Kuznets (1961a) estimate of \$27 billion and adding net capital formation in each year through 1929 from Kuznets (1961b) to create an annual series that runs through the benchmark points. Finally, we ratio-splice the resulting series for 1870–1925 to the later BEA series. The investment rate that appears in figure 8 is the ratio of our final investment to the capital stock series, expressed as a percentage.

⁵The stock market data are from the CRSP files and our backward extension of them to 1885. NYSE firms are available in CRSP continuously, AMEX firms after 1961, and NASDAQ firms after 1971. New listings are given by the total year-end market value of firms that entered our database in each year, excluding American depository receipts (ADRs).

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