Science-Based Business: Knowledge Capital or Entrepreneurial Ability?
Theory and Evidence from a Survey of Biotechnology Start-ups

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Abstract

The conventional view of science-based businesses focuses on the inseparability of the roles of the inventor generating the underlying idea and the Schumpeterian entrepreneur who implements it in practice. We present an equilibrium model of science-based entrepreneurship where scientific ideas and entrepreneurial ability of a scientist-entrepreneur are complementary resources that can be positively matched for an idea of certified good quality. If the costs of outside evaluation (certification) of an idea are not very high, there is a unique equilibrium where high-ability founders whose ideas are not good become free agents and are hired to develop good ideas for the startups with low-ability founders. The equilibrium is constrained efficient and a reduction in evaluation costs increases entrepreneurial turnover and improves welfare. We use novel data on the biotechnology startups in Japan and find evidence that is consistent with the theory and also with empirical studies of the U.S. biotechnology industry.

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The advent of science-based industries, such as biotechnology, has led economists to focus on the role of "star scientists" in the success of new business ventures (e.g., Zucker, Darby, and Brewer [1998]). According to the conventional view (e.g., Zingales [2000], Pisano [2010]) high-level knowledge capital is the "critical resource," and it is impossible to separate the roles of the "inventor" who generates the underlying scientific idea and the "innovator" (entrepreneur) who must implement it in the production process. Recent empirical studies have demonstrated, however, that founders are often replaced in venture capital-backed startups, even though the underlying core technology remains the same (e.g., Kaplan, Sensoy, and Strömberg [2009], most of whose evidence comes from biotechnology). Venture capitalists have been known to assume a pro-active role in changing the top management in high-tech startups that they finance (Lerner [1995], Kaplan and Strömberg [2001], Hellmann and Puri [2002]). This evidence conforms to the long-standing view in the economic profession that performing the entrepreneurial function requires a special set of skills that are distinct from those required to be a successful inventor (Schumpeter [1949]). In this paper, we present a theory and an empirical test of how entrepreneurial talent is reallocated to develop scientific ideas stemming from founder-specific knowledge capital.

We conjecture that the key to such a reallocation in a science-based industry is a mechanism that allows scientists to evaluate and certify high-quality ideas. We show that if the costs of evaluating ideas are too high, reallocation is impossible and the conventionalwisdom view of science-based industry prevails. However, as evaluation costs become lower, founders take advantage of the early opportunity to resolve the technical uncertainty inherent in science-based business, and more good ideas can be matched to high-ability scientists-entrepreneurs through an endogenously emerging market for entrepreneurial talent. In the ensuing reallocation equilibrium, both private and social returns to science-based businesses are higher.

We are not the first to model the relationship between entrepreneurial talent and business transfers (see, e.g., Holmes and Schmitz [1990] and [1995], Gromb and Scharfstein [2002], and Jovanovic and Braguinsky [2004]). But past literature has not addressed the issue of reallocation of entrepreneurial talent, which is the key issue in industries where ideas come from inventors-scientists. For example, in Holmes and Schmitz [1990], ideas (projects) move from founders-entrepreneurs to business managers to free up the entrepreneur who specializes in developing new ideas. In contrast, in our model, ideas coming from basic research must undergo costly, upfront evaluation before entrepreneurial talent can be freed and reallocated to implement those of them that are certified as good. One distinct empirical prediction from the theory is that, contrary to the "stylized fact" that CEO turnover is generally associated with subpar past performance (Weisbach [1988], Brickley [2003]), even before the founder is replaced, the average market valuation of the startups that subsequently replace founders by non-founder CEOs should be higher than the market valuation of those that don't.

The efficiency-improving reallocation of entrepreneurial talent can be fostered by policy measures aimed at better connecting inventors with industry experts and by developing the market for “hands-on” angel and venture capital financing. We examine these predictions using a novel dataset on Japanese biotechnology, which has been growing rapidly in the past decade after a series of broad institutional reforms.

Consistent with the model, we find a sharp increase in both entry and replacement rates of founders by non-founder CEOs among the post-reform entrants into Japan’s biotechnology industry. We also find that the startups that replace founders are already valued higher by the market even before the founder is replaced. We consider some alternative explanations for these patterns in the discussion section.

Our study implies that reducing founders’ relative costs of evaluating scientific ideas is a key condition for the reallocation of entrepreneurial talent necessary to promote successful science-based startups and improve welfare. In particular, it follows from both our theory and the empirical exercise that policy measures to promote science-based business should first and foremost be aimed at creating the mechanism connecting inventors to industry experts who can evaluate and certify good ideas and at developing the nation-wide market for science-related entrepreneurial talent.

In the next section we present the model. Section II analyzes the data. Section III contains discussion and considers some alternative explanations. Section IV concludes.

I. The model

A science-based startup has a founder with idea z, the quality of which is equal to 1 with probability λ and 0 with probability 1-λ. The founder's entrepreneurial ability is denoted by x. The value of the startup is equal to zx. Thus, the quality of the idea and the ability to develop it are complements.

A startup founder can hire another scientist-entrepreneur to develop the idea. If a founder with idea z hires an entrepreneur with ability x', the value of such a startup will be zx'. The hired entrepreneur receives a wage $w(x')$ and the founder claims the residual, $zx' - w(x')$. For simplicity, we assume that entrepreneurial ability is known, independent from z, and distributed among founders according to the cumulative distribution function $F(x)$ with strictly positive density over a finite support $[0, x_{\max}]$. All agents are risk-neutral and maximize their private expected values with no discounting of the future.

The founder may pay a cost $C > 0$ to learn the quality of z before developing it and perhaps also have it certified by a reputable outsider (e.g., Hsu [2004]). The parameter C can also be thought of as the cost of resolving the "technical uncertainty" surrounding the initial idea (Berk, Green, and Naik [2004], Hellmann and Perotti [2010]). If the founder pays C and discovers that $z = 1$, he either develops the idea himself or hires someone else to develop it. If z turns out to be 0, the idea is abandoned and the founder can be hired to develop the idea of another founder.

Hired entrepreneurs take the wage function $w(x)$ as given. We show later that unless C is very large, there is a "marginal" ability $\hat{x}$ such that any founder with $x \geq \hat{x}$ will be hired to develop someone else's good idea in case his own $z = 0$, while founders with $x < \hat{x}$ will not be hired to develop others' ideas. The marginal ability $\hat{x}$ "pins down" the wages received by all hired entrepreneurs because in equilibrium all good ideas are the same and hence founders with good ideas must be indifferent about which entrepreneur to hire. In other words, hired entrepreneurs receive efficiency wages, reflecting the differences in their ability (cf. Holmes and Schmitz [1990]). Denote the wage of the marginal hired entrepreneur by $w(\hat{x})$. The founder who hires $\hat{x}$ receives a payoff equal to $\hat{x} - w(\hat{x})$ from his idea, and all other founders must receive the same from hiring entrepreneurs of ability x. Hence, the wage function of hired entrepreneurs will be given by $w(x) = x - [\hat{x} - w(\hat{x})]$.

If a startup chooses to develop its idea by hiring an entrepreneur rather than having its founder develop the idea, we say by definition that such a startup experiences turnover in its CEO, with the founder replaced by a hired entrepreneur. In equilibrium, only startups with evaluated ideas may experience CEO turnover, while all unevaluated ideas are developed by founders alone. Even though we abstract from discounting of the future, we consider the fact that unevaluated ideas may be subject to an "obsolescence risk" that instantaneously destroys their total value (cf. Berk et al. [2004]). We denote by $\beta \leq 1$ the "survival probability" (one, minus obsolescence risk) of an idea with unknown quality.

To sum up, events occur in the following sequence:

1. A continuum of startups forms.
2. Startups choose whether to incur C and learn the quality z of their idea, which is publicly revealed. If z is 0, the startup exits and the founder becomes a free agent. If z is 1, the founder chooses whether to develop the idea on his own or to hire a free-agent entrepreneur.
3. The market for free-agent entrepreneurs clears with hired entrepreneurs of ability x receiving a competitive wage $w(x)$.
4. Ideas are developed and values are realized.

B. *Special case: no obsolescence risk*

In this section we derive the equilibrium under the special case of no obsolescence risk (that is, $\beta = 1$). Unless C is very large, there is a unique equilibrium in this case, where startups founded by individuals at high and low ends of entrepreneurial ability choose to evaluate their ideas and high-x entrepreneurs with useless ideas are hired to develop good ideas for low-x startups. Startups founded by individuals of intermediate x, on the other hand, choose not to incur the evaluation cost and do not hire entrepreneurs to develop ideas.

Key to equilibrium are two real numbers, $\tilde{x}$ and $\hat{x}$, where $\tilde{x} < \hat{x}$. These numbers divide the set of x-values into three regions – bottom, middle and top. We first describe founders' *ex ante* expected values in each region.

The Bottom Region: $x \leq \tilde{x}$ --- Startup founders in this region pay C and learn z. If z = 0 they exit and receive nothing, while if z = 1, they hire an entrepreneur x' from the top region and receive $x' - w(x') = \hat{x} - w(\hat{x})$. The *ex ante* expected value in this region is

$$E_L = -C + \lambda(\hat{x} - w(\hat{x})). \qquad (1)$$

The founder $\tilde{x}$ is indifferent between receiving the expected value given by (1) and developing the idea of uncertain quality with the *ex ante* expected value equal to

$$E_M = \lambda x. \qquad (2)$$

Hence, we must have

$$\tilde{x} = \hat{x} - w(\hat{x}) - C/\lambda. \qquad (3)$$

The Middle Region: $x \in (\tilde{x}, \hat{x})$ --- Startup founders in this region work on their own ideas of uncertain quality. Their *ex ante* expected value is therefore given by (2). Intuitively, startups in this region have too high x to be willing to pay for development by another entrepreneur, but are not good enough to pay for evaluation.

The Top Region: $x \geq \hat{x}$ --- Startup founders in this region pay C and learn z. If z = 1, they proceed to develop their own idea. If z = 0, they are hired by startups in the bottom region and receive $w(x) = x - [\hat{x} - w(\hat{x})]$. Their *ex ante* expected value is

$$E_H = -C + \lambda x + (1-\lambda)(x - \hat{x} + w(\hat{x})) = x - (1-\lambda)(\hat{x} - w(\hat{x})) - C. \qquad (4)$$

The founder $\hat{x}$ is indifferent between the expected values in (2) and (4):

$$\lambda\hat{x} = \hat{x} - (1-\lambda)[\hat{x} - w(\hat{x})] - C, \qquad (5)$$

so the equilibrium wage at $\hat{x}$ is given by:

$$w(\hat{x}) = C/(1-\lambda). \qquad (6)$$

Figure 1 illustrates the equilibrium behavior outlined above.

Figure 1. Equilibrium behavior by startup type

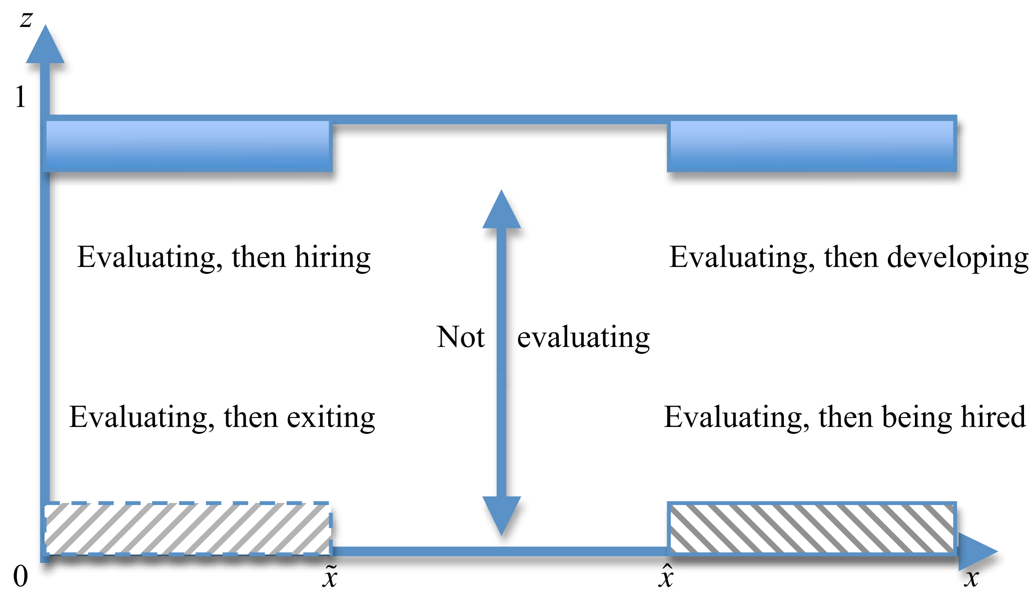
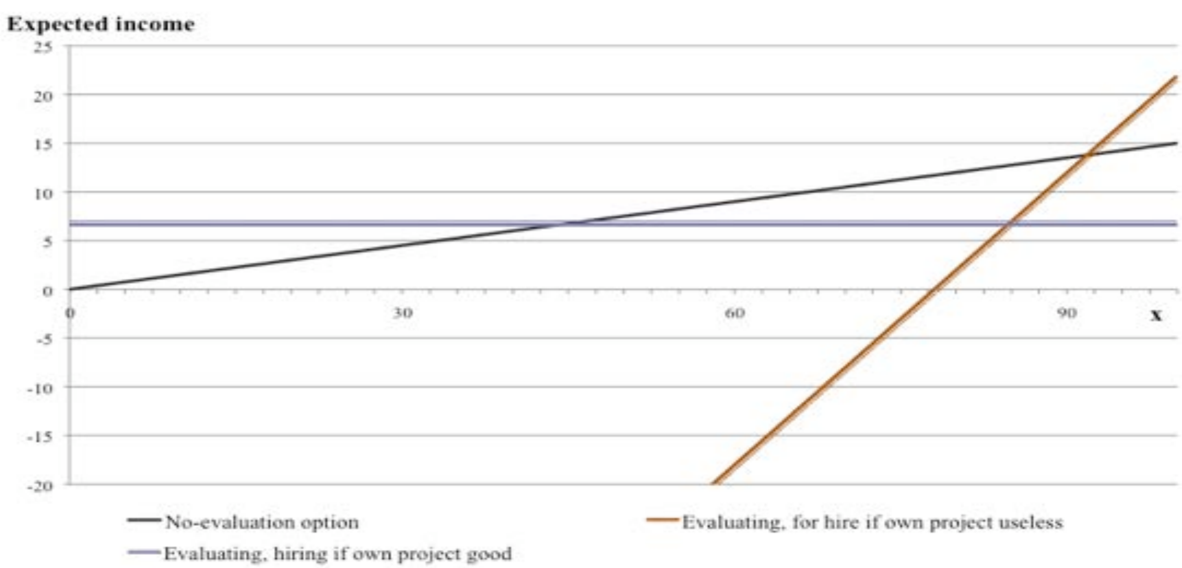


Figure 2 illustrates how expected values in (1), (2) and (4) depend on *x*.

Figure 2. Expected values and equilibrium (λ = 0.15, $C = 6$, $x_{max} = 100$)



Market Clearing. --- Demand for entrepreneurs must equal their supply:

$$\lambda F(\tilde{x}) = (1-\lambda)(1-F(\hat{x})). \tag{7}$$

Existence and uniqueness

If the evaluation cost C is too high, the only equilibrium is where all startups choose to develop their own ideas of unknown quality. To see this, notice that condition (3) implies that $\hat{x} - w(\hat{x}) > C/\lambda$ must hold in order for $\tilde{x}$ to be positive. Condition (4) then implies that the value of the evaluation option for the highest-ability entrepreneur is bounded from above by $x_{max} - (1-\lambda)C/\lambda - C = x_{max} - C/\lambda$. In order for the highest-*x* founder to be willing to incur the evaluation cost, this value needs to be greater than the value of the no-evaluation option λx_{max}. We thus have

Proposition 1 (No-evaluation equilibrium). *If $C \geq \lambda(1-\lambda)x_{max}$, all startups develop their own ideas of unknown quality and there is no entrepreneurial reallocation in equilibrium.*

Proof: By the argument immediately above, if $x_{max} - C/\lambda \leq \lambda x_{max}$, no startup finds it worthwhile to incur C to learn z. But all ideas are *ex ante* the same, so there is no gain for high-ability entrepreneurs to give up their own ideas in order to be hired to develop someone else's idea with equally uncertain quality.

We now turn our attention to relatively low-C environments.

Proposition 2 (Existence and uniqueness of equilibrium with evaluation). *If*

$$C < \lambda(1-\lambda)x_{max}, \tag{8}$$

idea evaluation and entrepreneurial reallocation occur in equilibrium. Furthermore, there *is a unique pair* $\{\tilde{x},\hat{x}\}\in(0,x_{\max})$, *where* $\tilde{x}=\hat{x}-C/\lambda(1-\lambda)$ *solves* (3), $\hat{x}>C/\lambda(1-\lambda)$ *solves* (6) *and the pair* $\{\tilde{x},\hat{x}\}$ *uniquely solves* (7).

Proof: Substituting $w(\hat{x})=C/(1-\lambda)$ from equation (6) into equation (3) we see that $\tilde{x}=\hat{x}-C/\lambda(1-\lambda)$ indeed solves equation (3). It remains to be shown that (i) for each value of λ and C that satisfy (8) there is a unique value of $\hat{x}$ that solves

$$\lambda F\left(\hat{x}-C/\lambda(1-\lambda)\right)=(1-\lambda)\left(1-F(\hat{x})\right), \tag{7'}$$

and (ii) there is no supply of ideas or demand for hired entrepreneurs coming from the middle region $x\in(\tilde{x},\hat{x})$.

Step (i). At $\hat{x}=C/\lambda(1-\lambda)$, the left-hand side of (7') is zero, while the right-hand side is positive, while at $\hat{x}=x_{\max}$ the left-hand side is positive, while the right-hand side is zero. Since x has strictly positive density over its support, the LHS of (7') is strictly increasing and the RHS is strictly decreasing in $\hat{x}$. Hence, exactly one intersection exists.

Step (ii). A startup founder hiring an entrepreneur with ability x pays the competitive wage given by

$$w(x)=x-\left[\hat{x}-w(\hat{x})\right]=x-\hat{x}+C/(1-\lambda). \tag{9}$$

Since a founder's *ex ante* expected value in the middle region is proportional to x, we only need to show that it will not be in the interest of the lowest-x founder among those to hire an entrepreneur to develop his idea, that is, that $\lambda(\tilde{x}+\varepsilon)>\lambda x-w(x)$ for any x and arbitrarily small ε. Substituting from (9) and noting that $\tilde{x}=\hat{x}-C/\lambda(1-\lambda)$, we obtain that

$\lambda\tilde{x} + \lambda\varepsilon - \left[\lambda x - w(x)\right] = (1-\lambda)(x - \hat{x}) + \lambda\varepsilon > 0$ for any x and $\varepsilon > 0$ since all free agent entrepreneurs for hire come from the top region where $x \geq \hat{x}$. This completes the proof.

Figure 3. The determination of the equilibrium $\hat{x}$.

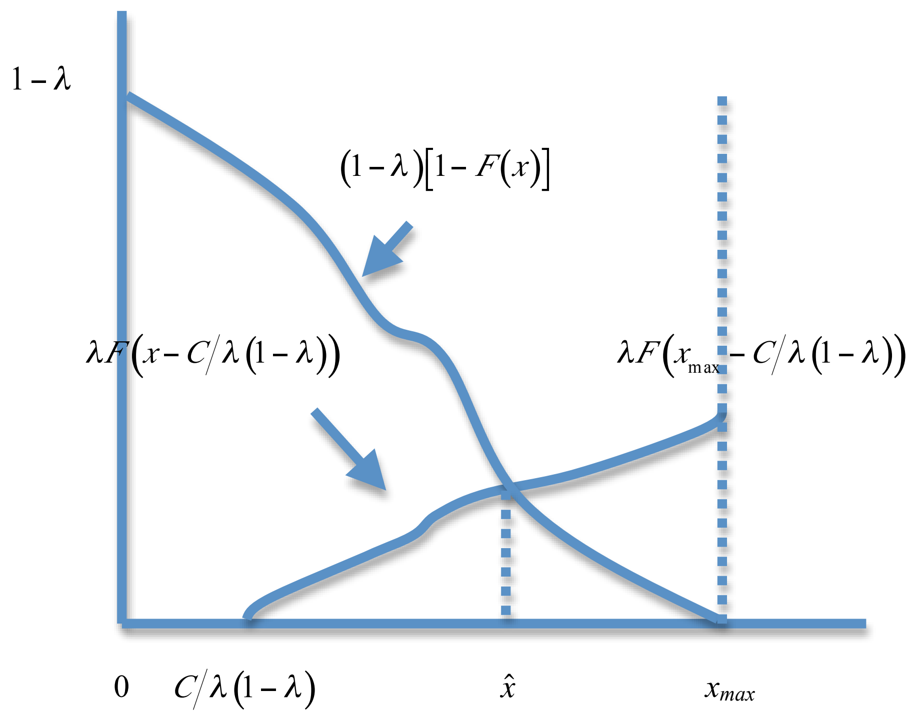


Figure 3 illustrates the determination of the equilibrium $\hat{x}$. The parametric example in Figure 2 above corresponds to the equilibrium where it is assumed that x is distributed uniformly on [0,100], giving $\hat{x} \approx 92$ and $\tilde{x} = 45$.

In equilibrium with evaluation, CEO turnover occurs if $x \leq \tilde{x}$ and $z = 1$, whereas no turnover occurs if either $x \geq \hat{x}$ and $z = 1$ *or* $\tilde{x} < x < \hat{x}$ and $z = 1$ with probability λ and $z = 0$ with probability 1-λ. Hence, turnover occurs only in cases where $z = 1$, whereas cases of no turnover are a mixture of cases $z = 0$ and $z = 1$. Moreover, hired entrepreneurs come from the top ability region where $x \geq \hat{x}$, whereas founders who develop unevaluated ideas among the startups that do not experience turnover come from the middle region where $\tilde{x} < x < \hat{x}$. With forward-looking markets, this reinforces the effect of the difference in idea quality between these two startup groups; specifically, firms that experience CEO turnover have certified higher average quality of ideas than firms that don't and are also expected to be managed by entrepreneurs with higher average ability. We thus have

Corollary. *Startups that subsequently experience CEO turnover will already have higher average market values early on (in Stage 2 above) than startups that do not experience CEO turnover.*

Welfare

The measure of welfare is the total value of all ventures. If no reallocation of high-*x* free-agent entrepreneurs with useless ideas to low-*x* startups with good ideas takes place, the total value would be $\lambda\mu \equiv \lambda\int_0^{x_{\max}} x\,dF(x)$. With reallocation, however, the total value, net of evaluation cost, becomes

$$V = \lambda\mu + (1-\lambda)\int_{\hat{x}}^{x_{\max}} x\,dF(x) - \lambda\int_{\hat{x}}^{x_{\max}} x\,dF(x) - C\left[F(\tilde{x}) + 1 - F(\hat{x})\right] \quad (10)$$

This is the value that could be attained if at a cost *C* the social planner could evaluate ideas for startups with $x < \tilde{x}$ and $x > \hat{x}$ and reassign free-agent entrepreneurs with $x > \hat{x}$ to develop good ideas in startups with $x < \tilde{x}$. The equilibrium maximizes *V* with respect to $\tilde{x}$ and $\hat{x}$, subject to the "resource constraint" (7).

Proposition 3. *The equilibrium assignment maximizes V. Moreover, when* $C < \lambda(1-\lambda)x_{\max}$, $dV/dC = -F(\tilde{x}) - [1 - F(\hat{x})] < 0$.

Proof: see appendix.

Proposition 3 says that if the planner must pay C for every discovery of a z=1 idea, the equilibrium also maximizes the aggregate value of all ventures, net of evaluation costs. In this sense, the equilibrium is constrained efficient (cf. Proposition 4 in Jovanovic and Braguinsky [2004]).

Comparative statics

Proposition 4. *The lower the evaluation costs C and the higher the fraction of good ideas* λ (*at least if* $\lambda < 0.5$), *the larger the fraction of startups that pay to evaluate the quality of the ideas and the larger the entrepreneurial reallocation in equilibrium.*

Proof: See appendix. Note that $\lambda < 0.5$ is a sufficient but not necessary condition for a higher fraction of good projects to lead to more entrepreneurial turnover in equilibrium.

C. *Equilibria with non-zero obselescence risk*

We now examine the general case where a startup developing a non-evaluated idea faces the exogenous risk of losing the whole value of the idea with positive probability $1-\beta$. The *ex ante* expected value of such a startup will thus be given by

$$E_M = \beta\lambda x, \qquad (2')$$

where $\beta < 1$ is the survival probability.

Most of the analysis in the previous section still goes through in this case but there are some differences. In particular, there is once again the no-evaluation equilibrium as in Proposition 1, but the condition under which such an equilibrium occurs is now given by $C \geq \lambda\left(1-\beta\lambda\right)x_{\max}$. Since the right-hand is decreasing in β, higher obsolescence risk makes the equilibrium with no evaluation less likely for the same values of parameters C and x_{max}. This is intuitive because if an idea is less likely to survive without being evaluated, the incentives to incur evaluation costs are stronger.

This intuition carries over to the case of equilibrium with evaluation. Specifically, there are now two possible types of equilibria with evaluation. The first type is similar to the equilibrium characterized in Proposition 2 and occurs if the obsolescence risk is relatively low. The second type occurs if the obsolescence risk is relatively high. In this case, all ideas will be evaluated in equilibrium and there will be no remaining ideas of uncertain quality. The following Proposition characterizes the two possible types of evaluation equilibria in the presence of non-zero risk of obsolescence.

Proposition 5. *If*

$$C < \lambda\left(1-\beta\lambda\right)x_{\max}, \tag{8'}$$

idea evaluation and entrepreneurial reallocation occur in equilibrium. Furthermore,

- *Either* $\hat{x} > \tilde{x}$ *where*

$$\hat{x} = \frac{\left(1-\lambda\right)\beta}{1-\beta\lambda}\tilde{x} + \frac{C}{\lambda\left(1-\beta\lambda\right)} \tag{11}$$

and $\hat{x} < C/\left(1-\beta\right)\lambda$ solves

$$\lambda F\left(\frac{1-\beta\lambda}{\beta(1-\lambda)}\hat{x}-\frac{C}{\beta\lambda(1-\lambda)}\right)=(1-\lambda)\left[1-F(\hat{x})\right], \tag{12}$$

- *Or* $\hat{x}\leq\tilde{x}$ *and* $\hat{x}\geq C/(1-\beta)\lambda$ solves

$$\lambda F(\hat{x})=(1-\lambda)\left[1-F(\hat{x})\right]. \tag{13}$$

In the latter case all ideas are evaluated in equilibrium.

Proof: see appendix.

The intuition behind Proposition 5 is that if the risk of obsolescence is too high compared to the cost of evaluation, then it is never optimal to hold on to an idea of unknown quality.

Proposition 5 implies that higher obsolescence risk works in the same direction as reducing evaluation costs by increasing the relative payoff to idea evaluation. Such a risk is most naturally associated with the actions of a competitor or changes in the environment (Berk et al. [2004], p. 2), so we expect more dynamic and competitive industries to have more high-ability entrepreneurs reallocated to develop good ideas. In other words, higher competition makes it unprofitable for founders of low ability to hold on to their ideas.

D. *Entry costs*

Founding a startup may entail paying some entry cost, which we denote by $b>0$. Then, in the no-evaluation equilibrium where each founder holds on to his own idea with uncertain quality, the expected value for startups in the range $x\in[0,b/\beta\lambda)$ is negative, so such startups are never formed. In the equilibrium with evaluation, on the other hand, their expected value is positive as long as $\hat{x}-\frac{C}{\lambda(1-\beta\lambda)}>b\frac{\beta(1-\lambda)}{\lambda(1-\beta\lambda)}$. Hence, for low enough C

(and not too high *b*) the presence of an entry cost will not deter startups from being formed. The intuition is that in the equilibrium with evaluation, all low-ability founders can expect to earn the same positive payoff given by $\hat{x} - w(\hat{x})$, regardless of their individual *x*, so a reduction in *C* (or an increase in obsolescence risk) will lead to the formation of a non-zero mass of new startups. Moreover, all those startups will choose to evaluate their ideas and will hire high-ability entrepreneurs if $z = 1$. We thus have

Proposition 6. *If there is a positive entry cost, lower evaluation cost and/or higher obsolescence risk may result in new entry by startups formed by low-ability founders. These new entrants will also be the primary candidates for CEO turnover.*

II. Founder replacement and startup performance in Japan's biotechnology industry

In this section, we analyze the data from the Japanese biotechnology. While the United States remains the world leader, Japan's biotechnology industry has been growing fast and became the second largest in the world in the number of university-based startups (Kneller [2007]), some of which have achieved considerable success even by global standards.[1] This followed a series of broad and far-reaching institutional reforms that in particular resulted in a big reduction in costs incurred by startup founders to have their ideas evaluated and certified. We first describe the data and the impact of institutional

[1] For example, AnGes MG, based on genetic research conducted at Osaka University, conducted the first successful IPO in the biotechnology industry in Japan in 2002 and has subsidiaries in the U.K. and the U.S.; MediNet, pursuing advanced immune-cell therapy for cancer and based on research conducted at the University of Tokyo (IPO in 2004), and so on.

reforms as related to the theory. We then examine whether the evidence can potentially falsify the model. Some alternative explanations are considered in the concluding section.

A. *The data*

We employ unique data from two representative surveys conducted by the Japan Bio Industry Association (JBA), a non-profit organization dedicated to the promotion of the Japanese biotechnology industry, with the support from the Hitotsubashi University Institution of Innovation Research (IIR) in 2008 and 2009.

The extended questionnaires designed jointly by JBA and IIR were sent out to 770 and 716 small- and medium-size biotechnology firms in 2008 and 2009 respectively. The numbers of responses was 309 in both years. We excluded firms conducting solely export-import operations and non-profit organizations conducting only R&D. Since some firms answered both surveys, we also excluded observations from the 2008 survey on the firms that answered both surveys. The remaining number of firms is 387, 106 of which were observed in 2008 and 281 were observed in 2009.

The information collected includes the year the firm was founded as well as the year in which it entered the biotechnology industry. For 93 percent of the sample the founding year and the year of entry are the same, so they are *bona fide* new startups. The questionnaires also asked whether the startup was managed by its founder at the time of the survey or if there had been a change in the CEO. In the latter case, the respondents were also asked to report the year the non-founder CEO was appointed. We also have information about major shareholders, venture capital funding, IPO events and plans, main R&D activity areas and patenting activity in Japan and in the United States. Information about the core technology, the amount of capital and the number of employees was collected both for the year the startup was founded and for the year of the survey.

Significantly, the sample is not limited to successful startups (such as VC-backed startups or startups that had already conducted an IPO). There is also large variation in market capitalization, R&D expenditure and the number of employees.

B. *An outline of institutional changes*

Japan introduced a large array of institutional and policy measures in the late 1990s – early 2000s to promote entrepreneurship, especially high-tech startups that transformed the environment for science-based businesses and made it resemble that in the United States. We argue that the most important such measures had a profound effect of lowering the costs of using outside expertise to evaluate and certify scientific ideas for their development potential, as well as the costs of starting new science-based ventures.[2]

The first set of measures involved changes in the industrial policy conducted by the Ministry of Economy, Trade and Industry (METI, formerly known as MITI). In post-World War II era this policy had been oriented towards supporting established companies rather than promoting innovative entrepreneurship. But in 1998 Japan enacted the Law for

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[2] There are several good sources in English that describe the reforms more generally: Rowen and Toyoda [2002], Schaede [2005], Kneller [2007].

Facilitating the Creation of New Businesses, closely modeled after the SBIR initiative in the United States. This was followed in 2000 by creating a National Forum for Business Startups and Ventures as well as incubator facilities providing consulting and support in management, technology, financing and legal affairs to startups. In 2004 several separate public corporations in charge were merged into the new publicly-run Organization for Small and Medium Enterprises and Regional Innovation (SMRJ), which has been given the task of providing one-stop support for innovative start-ups.

Our interviews with the management of biotechnology startups in Japan indicate that for many startups, taking advantage of these new opportunities represented the first chance to get an outside expert evaluation of their idea. Certification from METI and SMRJ experts is also apparently regarded as a strong positive signal by the capital market. By 2003 the sheer number of consultations conducted by METI regional consulting organizations totaled 95,000 cases (Schaede [2005]).

The second important change was the emergence of the U.S.-style "hands-on" venture capital funds and angel investors. In the United States, one of the most important roles of venture capital funds is to provide startups with expertise, advice, and certification of ideas (Hsu [2004], Kaplan and Strömberg [2001]). What was called "VC financing" in the pre-reform Japan, however, used to be indistinguishable from bank loans (Rowen and Toyoda [2002]). The reforms began with the Limited Partnership Act for Venture Capital Investment enacted in 1998, which improved the incentives to build up human resources and to secure assistance from outside specialists for newly created businesses. Several new venture capital funds emerged with the explicit goals of providing technology-business model evaluation and hands-on support as opposed to simply lending money to new startups.[3] This was complemented by the so-called Angel Tax Incentives measures introduced in 1997 and greatly expanded in 2000 and 2003 and by the New Business Financing Program in 2001 to provide loans without collateral to new high-tech businesses.

Finally, a series of legal changes drastically changed the university-industry relationship. Prior to the reforms, university researchers had to use a loophole in a regulation that allowed them to transfer rights to commercially exploit their inventions to industry in exchange for research donations. Companies were expected to pay only token royalties if the invention was commercialized; the cost of having an idea evaluated for its commercial potential was thus very high, resulting in a large number of "sleeping inventions" (Kneller [2007]).

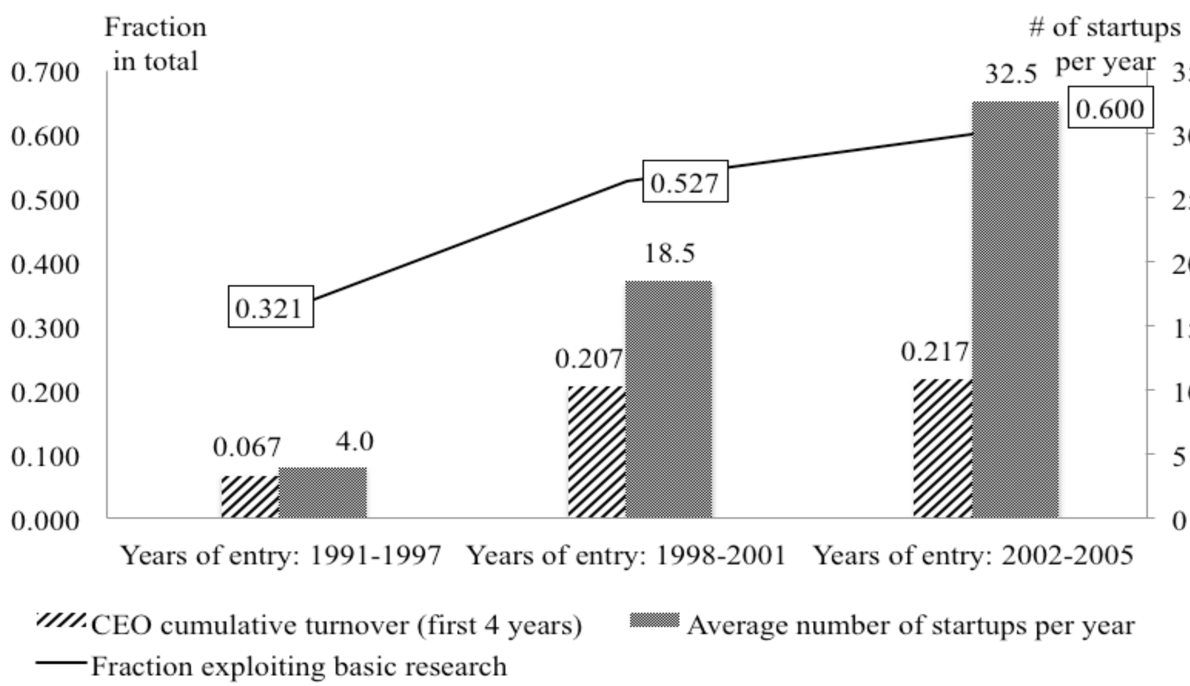
The 1998 TLO Law legitimized contractual transfers of university discoveries to industry. Then followed the 1999 Japan Bayh-Dole Law with its 1980 U.S. counterpart as the blueprint. The Law to Strengthen Industrial Technology enacted in 2000 allowed national university researchers to create and manage companies without having to resign their academic positions. Finally, the 2004 University Incorporation Law gave independent legal status to public universities, putting them under the jurisdiction of the Bayh-Dole Law.

[3] See, for example, http://www.ntvp.com/english.html, http://www.sip-vc.com/english/mission/index.html.

C. *Entry time, ideas exploiting basic research and CEO turnover*

The legal and regulatory changes summarized above led to a drastic reduction in the costs of having ideas evaluated and certified by outside experts for university scientists as well as the costs of launching their own startups (parameters *C* and *b* in the model in the previous section). We can thus compare the startups that entered the industry before and after the reforms to see if the reform effects conform with the predictions of the theory.

Figure 4. Number of startups per year, fraction exploiting basic research and founders' 4-year replacement rates by entry cohorts in Japan's biotechnology industry.



Source: authors' estimates based on JBA (Japan Biotechnology Association) surveys data. "Basic research" refers to research conducted in universities and/or public research corporations.

Figure 4 compares three cohorts of startups in Japan's biotechnology industry. The first cohort is comprised of the startups that entered from 1991 and until 1997, the period in the 1990s before the reforms began in earnest. The second cohorts represents the startups that entered during the four years of early reforms (1998-2001), while the third cohort contains the startups that entered from 2002-2005, during the late stage of the reform.

The average number of startups per year increased sharply and the fraction of startups whose core technologies exploited research ideas developed in universities or public research corporations almost doubled from the pre-reform to post-reform years, so new businesses were indeed predominantly science-based. While both these findings are not particularly surprising, what is more surprising is the three-fold increase in early replacement rates of founders by non-founder CEOs in the two later cohorts as compared to the pre-reform cohort. In other words, more science-based later startups were more likely to quickly replace the founder with a non-founder CEO.

We now look at this evidence more formally. Specifically, we conduct a probit regression with the dependent variable the probability of the startup founded based on an idea coming from a university or public research corporation and a hazard regression with the dependent variable the annual hazard of CEO change. Each firm-observation is assigned a 1-0 dummy variable depending on the entry cohort it belonged to. The annual hazard of CEO change is estimated by a Cox proportional hazard model, which obviates having to specify how startup age affects the hazard. All standard errors have been computed by clustering observations for each startup. We also include seven 1-0 dummies capturing the main area of R&D activity of the startup.

Table 1 presents the estimation results. In the probit regression, the probability of core technology coming from a university or public research corporation is estimated to be 30.7 percent higher for the latest cohort of entrants than in the baseline cohort of pre-reform entrants and 24.2 percent higher for the cohort of entrants from 1998-2001. The difference between the two coefficients themselves, however, is not statistically significant.

Table 1. Entry cohorts, source of core technology and CEO change hazard rates

		Probit regression		Cox proportional hazard regression	
		Dependent variable: core technology from basic research		Dependent variable: annual hazard rate of CEO change	
Entry cohort dummies (baseline cohort: entrants before 1998)					
2002 and later	Coefficient	0.307	***	5.931	***
	St.Error	0.080		2.173	
From 1998-2001	Coefficient	0.242	**	4.657	***
	St.Error	0.088		1.693	
Area activity controls		Included		Included	
Number of observations		276		1996	
Number of startups		276		290	
Log likelihood		-182.211		-538.622	

Note: Authors' estimates using JBA survey data. *** and ** indicate that the coefficient is significant at 1 and 5 percent levels, respectively. Probit regression coefficients show marginal effects. Startups in the hazard regression include also those that did not report the source of its core technology.

In the hazard regression, annual hazard rates of CEO change are 5.9 times higher for the entrants in the post-2002 cohort than in the baseline entry cohort and 4.7 times higher in the cohort of entrants in 1998-2001. The difference between the two later cohorts is not statistically significant at conventional levels. It thus appears that even though the legal framework for university researchers to start their own independent companies was not completely in place until 2004, the reduction in the costs of outside expertise and drawing on external human resources resulting from the measures put in place in the late 1990s had already created most of the conditions needed to launch science-based startups and recruit outside entrepreneurs to develop ideas. We also estimated CEO hazard rates for the cohort of pre-1998 entrants before and after the reform. The estimation results (not shown) imply that after 1998 the hazard rates were about 2.8 higher than before for those entrants.

The U.S. data suggest that even the more recent founder replacement rates in Japan may still be relatively low. In a study using early SPEC (Stanford Project on Emerging Companies) data, Hannan, Burton, and Baron [1996, Table 1] estimate the cumulative first 4-year hazard rates of founder-CEOs in young high-tech firms to be about 40 percent.

D. *CEO turnover and Stage-2 market values*

The Corollary to Proposition 2 states that the average market value of the surviving startups that experience CEO turnover should be higher already at the time of entry (that is, *before* the founder replacement event) than the average market value of the startups that are managed by their founders. This is perhaps the most distinctive and also somewhat counterintuitive prediction from the theory. To test it, we conduct the "pre-program" regression in which capital in entry year is regressed on subsequent replacement of founder by a non-founder CEO. The future CEO (who may not be appointed for several years after entry) can, of course, have no direct "causal" effect on the capital raised by the startup at the time it enters the industry. Hence, a positive estimated coefficient on the dummy reflecting subsequent CEO change would be an indicator of the presence of positive selection on the quality of the startup associated with subsequent founder replacement, as predicted by the theory (cf. Jovanovic and Moffitt [1990]).

Table 2. Capital at entry and entrepreneurial turnover

		Dependent variable: Log capital at entry			
Non-founder CEO dummy	Coefficient	0.738	***	0.747	***
	St.Error	0.248		0.247	
Other startup characteristics at foundation time (1-0 dummies):					
Core technology exploiting basic research	Coefficient			-0.394	
	St.Error			0.263	
Founder largest shareholder	Coefficient			-1.174	***
	St.Error			0.261	
VC financing	Coefficient			-0.185	
	St.Error			0.560	
Patent activity in the US	Coefficient			0.733	***
	St.Error			0.263	
Entry year and R&D activity area dummies		Included		Included	
Constant	Coefficient	2.119	***	3.038	***
	St.Error	0.610		0.654	
Number of observations		233		218	
Number of startups		233		218	
Adjusted R-squared		0.051		0.190	

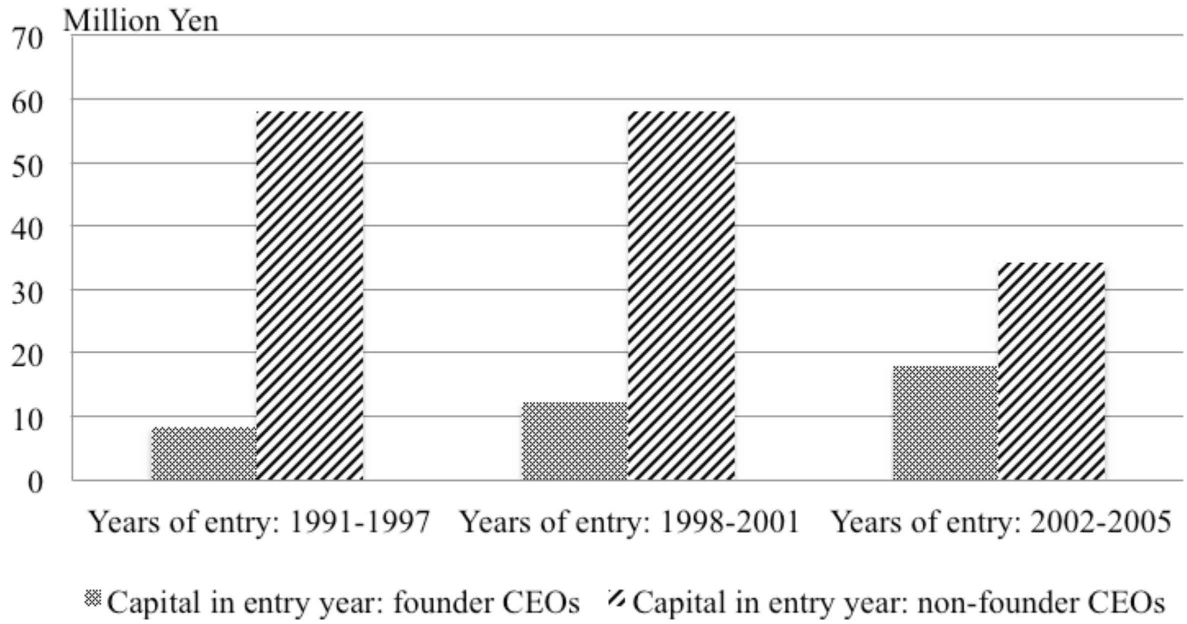
Note: Authors' estimates using JBA survey data. *** indicates that the coefficient is significant at 1 percent level.

Table 2 presents the estimation results. We regress the (log of) capital in the year of entry on the dummy equal to 1 if by the time of the survey, the startup had replaced its founder and 0 if it had not. The identifying assumption is that all startups are equally likely to replace founders for reasons unrelated to our theory. We control non-parametrically for firm age by including all 34 entry year dummies and also for R&D areas. In addition, the specification in the second column includes the 1-0 dummies capturing other entry-year characteristics of the startup, which may reflect its capital-raising ability; the source of core technology, whether the founder is the largest shareholder, VC financing at the time of entry and patents applied for or granted in the U.S.

The results are consistent with the model. Subsequent change from the founder to a non-founder CEO is associated with 109 percent (exp(0.738)-1) higher entry-year capital in the first column and with 111 percent higher entry-year capital in the second column. The estimated coefficient on the CEO turnover dummy is practically unaffected by other characteristics included in the specification in the second column. The effects of those characteristics themselves are for most part in line with expectations; having a patent granted or applied for in the U.S. roughly doubles the initial capital-raising capacity, while having the founder as the largest shareholder reduces this capacity by about 2/3.

The econometric estimation results above can be clearly confirmed in raw data. Figure 5 shows that the startups that subsequently replaced founders with non-founder CEOs were indeed valued higher by the market than the startups that continued to be managed by their founders already in their entry year. The picture would have looked essentially the same had we used the initial size measured by the number of employees instead of initially raised capital.

Figure 5. Capital in entry year (millions of yen) and founder replacement by entry cohorts in Japan's biotechnology industry.



Source: authors' estimates based on JBA (Japan Biotechnology Association) surveys data.

E. *CEO turnover and market value at the time of the surveys*

In theory, higher entrepreneurial ability in startups with non-founder CEOs implies that they will also have higher Stage-4 market values than those with founder CEOs. However, since the only startups to survive to Stage 4 are those with $z = 1$, the model also implies that the gap between the Stage-4 market values of the two groups should be less than the gap between their Stage-2 market values.

In the data analysis above we could use entry-year capital as a reasonable proxy for Stage-2 market values in the model. Using capital at the date of the survey as a proxy for Stage-4 market values is more problematic. First, some startups, especially younger ones, will still have ideas of uncertain quality. Second, investment in developing good ideas in reality happens in stages, so that startups with evaluated $z = 1$ will keep raising more capital as they move forward, increasing rather than decreasing the gap with the startups that wait for the resolution of the uncertainty surrounding their ideas.

Nevertheless, it is instructive to take a look at the differences in capital observed at the time of the surveys between the two groups of startups, if only because this presents an opportunity to refute the theory. The argument in the previous paragraph suggests that we may not be able to find evidence of a narrowing gap between the capital raised by the startups that had experienced CEO turnover by the time the startups were surveyed and those that hadn't as compared to entry-year capital. But if we find that this gap disappears or is even reversed, that would be clearly inconsistent with the model. Also, once we control for entry-year capital, we would expect the effect of CEO turnover on contemporaneous capital to be much weaker than without such control.

The first column in Table 3 indicates that capital at the time of the survey remains strongly positively associated with the non-founder CEO dummy when only firm age and areas of R&D are controlled for. The magnitude of the coefficient is about 17 percent smaller than the corresponding magnitude of the coefficient in Table 2.

The magnitude of the coefficient on the non-founder CEO dummy in the second column, on the other hand, is just about 1/3 of the coefficient in the first column and it is statistically not significant at conventional levels. Once again, the results would look almost the same if we used employment or R&D expenditure rather than capital at the time of survey as the dependent variable.

Table 3. Entrepreneurial turnover and contemporaneous capitalization

Dependent variable: Log capital at time of survey					
Non-founder CEO dummy	Coefficient	0.609	***	0.229	
	St.Error	0.217		0.197	
Log capital at entry	Coefficient			0.237	***
	St.Error			0.057	
Other startup characteristics					
Core technology from basic research dummy	Coefficient			0.018	
	St.Error			0.202	
Founder the largest shareholder dummy	Coefficient			-0.738	***
	St.Error			0.207	
Venture capital financing dummy	Coefficient			1.117	***
	St.Error			0.223	
Patent activity in the US dummy	Coefficient			0.573	***
	St.Error			0.206	
Entry year and activity area dummies		Included		Included	
Constant	Coefficient	2.741	***	2.279	***
	St.Error	0.667		0.664	
Number of startups		277		246	
Adjusted R-squared		0.267		0.506	

Note: Authors' estimates using JBA survey data. *** indicates that the coefficient is significant at 1 percent level.

III. Aternative explanations and discussion

Higher founder replacement rates in post-reform startups can perhaps also be explained by a simpler view that new startups founded by former academics lack the knowledge of industry and management skills and there are just more of them after the reforms. But this explanation alone cannot account for the evidence that the startups that eventually replace founders are already valued higher by the market *before* the founder is replaced. In contrast, our model of reallocation contains the mechanism to explain this evidence because idea evaluation represents a signal coming from those startups to the market right off the bat.

It is also possible that larger startups tend to hire specialized entrepreneurs simply because they have more to gain from specialization. This explanation can also generate a positive relationship between initially raised capital and subsequent founder replacement as does our model. The specialization story by itself, however, does not explain why post-reform entrants should have significantly higher founder replacement rates than pre-reform entrants even after we control for both entry size and the source of the core technology.

Non-pecuniary motivation

In this paper, we modeled founders as agents interested only in maximizing expected earnings. This may not be the case, especially in the case of scientists, if non-pecuniary motives that presumably were at least partly responsible for their initial choice of the academic career (e.g., Stern [2004]) remain in place even after they move to found science-based startups. Wasserman [2008] presents an alternative explanation for an equilibrium where less successful startups managed by their founders coexist with more successful startups where founders turn the control over to outside CEOs. Building upon formidable previous literature (e.g., Hamilton [2000], Moscowitz and Vissing-Jorgensen [2002]), he argues that profit-generating turnover from founders to better entrepreneurs may be hampered by the extra utility component of retaining control.

While non-pecuniary motives are not the focus of our theory, it can accommodate them if the parameter C is interpreted inclusive of the utility cost of evaluating the idea and potentially learning that it is useless. The equilibrium with reallocation derived in Section II then simply implies that if such utility costs are not prohibitively high, founders with high and low entrepreneurial ability who have high potential pecuniary gains from evaluation and subsequent reallocation will choose to incur the utility costs of evaluating their ideas, whereas founders with intermediate ability will choose not to evaluate and will try to develop their ideas on their own.[4] An interesting consequence of reinterpreting the model in this way is that if there are cross-cultural differences in utility costs, the evaluation cost parameter in the model will vary across countries even if all other things are the same.[5]

IV. Conclusion

Science-based business in general and biotechnology in particular are a growing and very important part of economic activity, and one would hope that startups in those areas could benefit from efficient reallocation of entrepreneurial talent to increase the returns to good ideas and welfare more generally. The crucial role of star scientists in founding

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[4] In his study of independent Canadian inventors who paid for an outside expertise of their ideas, Astebro [2003] found that many of them still pursued their ideas despite a negative recommendation. Presumably, the *ex post* utility of those inventors could have been improved had they not sought the expertise in the first place.

[5] In his homepage http://founderresearch.blogspot.com/2008/07/rich-vs-king-around-world.html, Wasserman presents evidence showing that Japanese founders attach higher utility to independence than do U.S. founders. This may explain at least part of lower turnover rates from founders to non-founder CEOs in our data on Japan as compared to the U.S. data noted above.

science-based startups has raised doubts that such a reallocation can take place and that as a result, science-based startups may be dysfunctional.

In this paper we have proposed a theory where early idea evaluation gives rise to endogenous emergence of both the supply of and the demand for high-ability entrepreneurs to be reallocated to implement certified good science-based ideas. We found that the institutional reforms recently introduced in Japan with the aim of creating a mechanism for such an evaluation produced empirical patterns consistent with the predictions from the theory. In particular, the theory has provided an explanation for the "counterintuitive" piece of evidence showing that startups replacing founders by non-founder CEOs do better from the very beginning than startups that don't replace founders, that is, *before* a new CEO can have any effect on performance.

Our study has important policy implications for countries trying the follow the United States' and Japan's footsteps. Reducing costs of evaluating scientific ideas requires developing an efficient linkage from university research to industry, including but not limited to creating access to outside expert bodies, promoting hands-on venture capitalists and angel investors. The science-based industry also needs to be dynamic and highly competitive in order to reduce potential payoffs to "mothballed" inventions.

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Appendix

Proof of Proposition 3.

The Lagrangian is $L(\tilde{x},\hat{x},\theta)=V+\theta\left\{\lambda F(\tilde{x})-(1-\lambda)\left[1-F(\hat{x})\right]\right\}$. The first-order conditions are

$$-(1-\lambda)\hat{x}+C+\theta(1-\lambda)=0,$$

and

$$-\lambda\tilde{x}-C+\theta\lambda=0.$$

The second-order derivatives with respect to $\tilde{x}$ and $\hat{x}$ are negative and the cross partials are zero. Therefore, L is globally strictly concave in the vector $(\tilde{x},\hat{x})$. Combining the two conditions and noting (7) proves the first claim. The second claim follows from the Envelope theorem.

Proof of Proposition 4.

Totally differentiate the equilibrium condition (7') to obtain

$$\left[\lambda f(\tilde{x})+(1-\lambda)f(\hat{x})\right]d\hat{x}-\frac{f(\tilde{x})}{(1-\lambda)}dC+\left[F(\tilde{x})+\left(1-F(\hat{x})\right)+\lambda f(\tilde{x})C\frac{1-2\lambda}{\lambda^2(1-\lambda)^2}\right]d\lambda=0$$

Hence, we have

$$\frac{\partial\hat{x}}{\partial C}=\frac{f(\tilde{x})}{(1-\lambda)\left[\lambda f(\tilde{x})+(1-\lambda)f(\hat{x})\right]}>0,$$

and

$$\frac{\partial\hat{x}}{\partial\lambda}=-\frac{\left[F(\tilde{x})+\left(1-F(\hat{x})\right)+\lambda f(\tilde{x})C\frac{1-2\lambda}{\lambda^2(1-\lambda)^2}\right]}{\left[\lambda f(\tilde{x})+(1-\lambda)f(\hat{x})\right]},$$

which will be less than zero if $\lambda<0.5$ (which is a sufficient, but not necessary condition).

Proof of Proposition 5.

The proof is by construction. To begin with, notice that for $\hat{x}$ close to $C/(1-\beta\lambda)\lambda<C/(1-\beta)\lambda$ the left-hand side of (11) tends to zero, while the right-hand side

tends to $(1-\lambda)\left[1-F\left(C/(1-\beta\lambda)\lambda\right)\right]>0$, since $x_{\max} > C/(1-\beta\lambda)\lambda$ by assumption. Also the left-hand side of (11) is strictly increasing in $\hat{x}$, while the right-hand side is decreasing in it. There are two possible cases.

--- Case (i). There is some $\hat{x}^* < C/(1-\beta)\lambda$ such that (11) is satisfied with equality at $\hat{x}=\hat{x}^*$. Conditions (10) and (11) yield, after some manipulations, that $\hat{x}>\tilde{x}$ at this $\hat{x}^*$. Then (11) and (10) imply that the number of entrepreneurs from the top region moving to work with projects owned by the startups with $z = 1$ in the bottom region is $\lambda F(\tilde{x})=(1-\lambda)\left[1-F(\hat{x})\right]$. Hence, (11) is indeed the desired equilibrium.

--- Case (ii). Assume now that at $\hat{x}=C/(1-\beta)\lambda$ there is still excess supply of entrepreneurs for hire (the left-hand side of (11) is smaller than the right-hand side). This means that $\hat{x}$ has to go up further. But if $\hat{x}>C/(1-\beta)\lambda$, the no-evaluation option becomes less attractive than paying C and letting another entrepreneur develop the project if $z = 1$ for founder $\tilde{x}$, so that only the bottom region $x\in[0,\hat{x})$ and the top region $x\in[\hat{x},x_{\max}]$ remain as part of an equilibrium (notice that $\hat{x}\le\tilde{x}$ if and only if $\hat{x}\ge C/(1-\beta)\lambda$). Since the left-hand side of (12) tends to $\lambda > 0$ as $\hat{x}\to x_{\max}$, while the right-hand side tends to zero as $\hat{x}\to x_{\max}$, there will be some $\hat{x}^*\in\left(C/(1-\beta)\lambda, x_{\max}\right)$ such that the equilibrium condition (12) is satisfied with equality. Note that in case (ii) founder $\hat{x}^*$ is indifferent between paying C and receiving $\hat{x}-w(\hat{x})$ with probability λ, on the one hand, and choosing the evaluation option with the expected private value E_H as in (4), on the other hand. Hence, we must have $\lambda\left(\hat{x}-w(\hat{x}^*)\right)-C=\hat{x}^*-(1-\lambda)\left(\hat{x}^*-w(\hat{x}^*)\right)-C$, or $w(\hat{x}^*)=0$. In other words, the *ex post* marginal hired entrepreneur's competitive wage is zero, equal to his opportunity cost of exit.