Internet Appendix for: Competition and R&D Financing: Evidence from the Biopharmaceutical Industry

Richard T. Thakor* and Andrew W. Lo†

*University of Minnesota - Carlson School of Management, and MIT LFE. 321 19th Avenue South, 3-255, Minneapolis, MN 55455. Phone: (612) 626-7817. E-mail: rthakor@umn.edu

†MIT Sloan School of Management, CSAIL, and NBER, 100 Main Street, E62–618, Cambridge, MA 02142. E-mail: alo-admin@mit.edu

Analysis of the Formal Theoretical Model

A.1 Actors and Preferences

Consider a biopharmaceutical firm that faces a decision to undertake a staged R&D investment. There are two periods with three dates: $t = 0$, $t = 1$, and $t = 2$. At $t = 0$, the firm chooses an amount to invest in either assets in place (such as existing products) or in R&D (for new products). If it chooses to invest in an R&D project, the project has two stages. At $t = 0$, the first-stage investment is made. At $t = 1$, the second-stage investment is made.

At both of these dates, the firm may need to raise capital and can choose between issuing equity and debt. This external financing is raised in an environment of adverse selection. Specifically, there are two types of firms: good firms and lemons. The common prior is that the probability of a randomly chosen firm being good is $g \in (0.5, 1)$ and being a lemon is $1 - g$.[1] The lemons are firms that lack the ability to produce R&D products, so their R&D investment produces no payoffs and their assets decline in value over time and also produce no cash flows.[2] The good firms are described below. The firm *privately* knows at $t = 0$ whether it is good or a lemon. Given this private information, we will model this as a game in which the informed firm moves first with its capital structure decision about how much financing to raise for R&D (and when to raise it). The uninformed capital market reacts to the firm's choice, and makes Bayesian rational inferences about the firm's payoffs, which then result in prices for the firm's securities.

At the final date, $t = 2$, all payoffs are realized, and shareholders and bondholders are paid off.

All agents are risk-neutral. The risk-free rate for a single period is $r > 0$ and is intertemporally constant.

[1] The lower bound on g is to avoid a corner solution by ensuring that there are sufficiently many good firms to allow financing to be raised.

[2] This could be due to mismanagement or outright fraud. The lemons are able to produce what appears to be successful first-stage R&D results, but the R&D is still worthless for these firms, since they are not able to produce any cash flows.

A.2 Investment Choices and the Effect of Competition

Let $A > 0$ denote the firm's investment in existing products and assets in place, and $R > 0$ its investment in R&D. Given managerial capacity constraints, we take the total investment size to be fixed at I. Thus, $A + R = I$, so the firm invests a certain proportion of its capital in assets in place and the remaining proportion in R&D. Our goal is to examine how A and R are determined. Since we are modeling an R&D-intensive firm, we can think of A as consisting mainly of existing patents and products on which patents have expired, but the products are still being produced and sold.

There are two states of the macroeconomy: an "up" state and a "down" state. The up state occurs with probability p, and the down state occurs with probability $1-p$. When the up state occurs, the firm's existing products pay off $x_H(A)$, and when the down state occurs they pay off $x_L(A)$, with $x_H(A) > x_L(A)\ \forall\, A > 0$. That is, the payoff from existing products is perfectly correlated with the state of the economy. It is assumed that the NPV of investing in assets in place is non-negative, even if the down state occurs: $x_L(A)[1+r]^{-2} \geq A\ \forall A$. We impose the standard assumptions on the production function $x\,(A)$:

$$\partial x_H/\partial A > \partial x_L/\partial A > 0, \quad \partial^2 x_H/\partial A^2 < 0,$$

$$\partial^2 x_L/\partial A^2 < 0, \quad \left|\partial^2 x_H/\partial A^2\right| > \left|\partial^2 x_L/\partial A^2\right|, \tag{1}$$

We now model the effect of product market competition. If the degree of competition is $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$, then a competitor arrives with probability θ. If this happens, the firm's profitability on existing products declines. Thus, a higher θ means greater product market competition.[3] For simplicity, we assume that when a competitor enters, the payoff of assets

[3] In our model, changes in competition θ can be interpreted as structural changes in the industry or other changes in competition that are exogenous to the individual firm. Important drivers of competition to industries such as biopharma are exogenous technology or regulatory shocks that lower entry costs. For example, the Human Genome Project represented a technology shock that was plausibly exogenous to any individual firm's decision, and it led to the entry of numerous small biotech firms into the industry. Another example is the Hatch-Waxman Act, which was a source of exogenous variation in competition for the biopharma industry, and something we use for identification purposes later in our analysis. However, since

in place in the up state becomes $x_L(A)$, an effect analogous to Bertrand competition.[4] This can be interpreted as a decline in the maximum markup firms will charge when competition increases.

Investment in R&D involves two phases. At $t = 0$, the firm makes its first-stage R&D investment R. Then, if it observes at $t = 1$ that the successful state has occurred for R&D, it must invest a larger additional amount $\hat{\omega}R$, $\hat{\omega} > 1$, in order to realize the payoff conditional on success. This larger second investment reflects the escalating resource commitments for subsequent clinical R&D trials that biopharma firms face (see DiMasi, et al. (1991)). Absent this second-stage investment, the R&D payoff at $t = 2$ is zero.

If the firm invests R in R&D at $t = 0$, then at $t = 1$ it becomes publicly known whether the first-stage R&D was very successful, modestly successful, or failed. The probability of the first-stage R&D being very successful is $q_+ \in (0, 1)$, the probability of it being modestly successful is $q_- \in (0, 1)$, and the probability of failure is $1 - q_+ - q_-$. However, this observation does not resolve the uncertainty about whether the firm is good or a lemon, since the lemon firm can be in each of these three observable first-stage R&D outcome states as well, just like the good firm. If the firm is truly a lemon, however, then the second-stage R&D payoff is zero at $t = 2$, regardless of the first-stage R&D outcome at $t = 1$. If the firm is good, then the R&D payoff at $t = 2$ is a random variable $\tilde{y}$, where $\tilde{y}$ is zero almost surely if the first-stage R&D fails at $t = 1$, has a probability density ξ_+ if the first-stage R&D is very successful at $t = 1$, and a probability density ξ_- if the first-stage R&D is modestly successful at $t = 1$. We assume that ξ_+ first-order stochastically dominates ξ_-. The expected payoffs are:

$$\int \tilde{y}\xi_+ d\tilde{y} = y_+(R) + B > 0, \tag{2}$$

R&D by incumbents can also affect the degree of competition, some portion of the degree of competition is endogenous (e.g., Gans and Stern (2000)). Our empirical tests are designed to tackle this potential endogeneity.

[4]In other words, the incumbent firm and the competitor would each set their prices for existing products lower in order to undercut each other, thus reducing profitability. We model this directly through a reduction in profitability. Although not necessary for the analysis, we could assume that the present value of $x_L(A)$ is A, i.e., that competition reduces the NPV of existing assets to zero. This would correspond to the situation in Bertrand competition, where firms set their prices equal to their marginal costs.

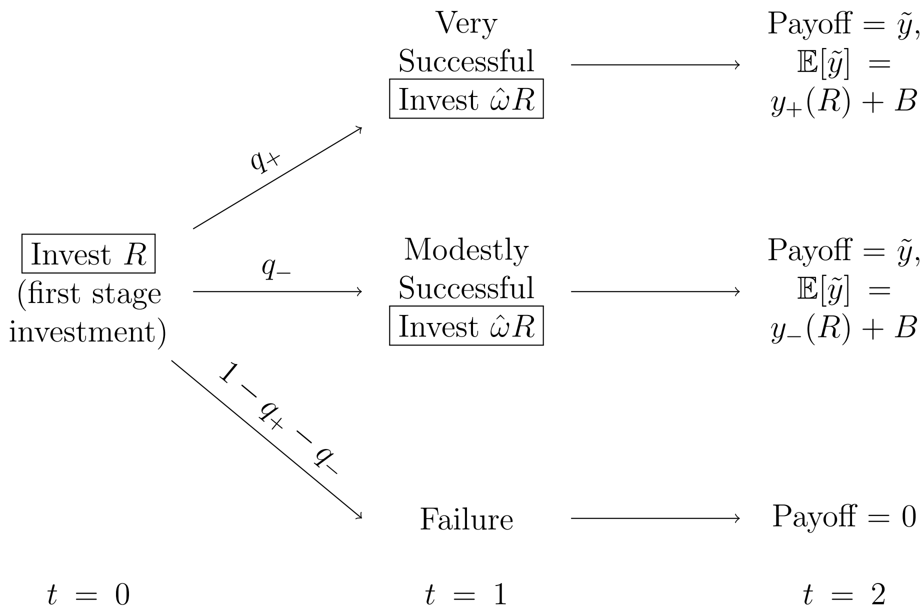

Figure A1: R&D Payoff Distribution Over Time

$$\int \tilde{y}\xi_- d\tilde{y} = y_-(R) + B > 0, \tag{3}$$

where $y_+(R) > y_-(R)\ \forall R > 0$, $y_+(0) = y_-(0) = 0$, and $B > 0$ is a non-contractible benefit of R&D to the insiders of the firm that cannot be verified and pledged to investors to make payments. We interpret B broadly to represent intangible knowledge payoffs that do not necessarily produce cash flows immediately, such as learning benefits for employees, generation of non-commercializable basic research knowledge, or potential future payoffs that may be expected to occur beyond the investment horizons of investors. We assume that the larger the investment in R&D, the larger the expected payoff:

$$\partial y_+/\partial R > 0, \quad \partial y_-/\partial R > 0,$$

$$\partial^2 y_+/\partial R^2 < 0, \quad \partial^2 y_-/\partial R^2 < 0. \tag{4}$$

The R&D payoff distribution is given in *Figure A1*.

We assume that R&D output is patent-protected, and hence immune to competitive pressures. Thus, the arrival of the competitor has no impact on the firm's R&D payoff.[5] In other words, changes in θ affect the profitability of existing assets, which have largely exhausted their patent protection, and are thus vulnerable to competitive pressures, relative to new, patent-protected drugs that have greater immunity to competitive pressures. This assumption is consistent with the effect of the Hatch-Waxman Act on patent-possessing firms that exploit in our empirical analysis.

The payoffs of assets in place and R&D are taxable at a rate of $T \in (0,1)$. We assume that the cash flows of the R&D investment of the good firm (i.e. the pledgeable portion of the payoff) create value, and thus there is positive NPV at $t = 0$ to the firm's insiders as well as investors, so:

$$[q_+ y_+ + q_- y_-]\,[1+r]^{-2}\,(1-T) > R + \hat{\omega} R\,[1+r]^{-1} \quad \forall R > 0. \tag{5}$$

We further assume that

$$\hat{g} y_- [1+r]^{-1}(1-T) < \hat{\omega} R, \tag{6}$$

$$y_- [1+r]^{-1}(1-T) + B > \hat{\omega} R + R, \tag{7}$$

$$B < \hat{\omega} R. \tag{8}$$

where $\hat{g}$ is the posterior belief of investors that the firm is good, conditional on a good signal being received by bondholders; $\hat{g}$ will be expressed explicitly later. Condition (6) implies that investors will be unwilling to provide financing at $t = 1$ if the R&D is discovered to have either failed or is only modestly successful, even if the bondholders' signal is good. Condition (7) implies that the firm's insiders will wish to invest $\hat{\omega} R$ at $t = 1$ even if the R&D is discovered to be modestly successful, and will also view this investment as beneficial at $t = 0$, taking into account the initial investment of R. Finally, condition (8) ensures that the value of the non-contractible benefits to insiders is not so large as to justify an investment

[5] Of course, when the patent expires, these products become part of the firm's assets in place and are then subject to losses in profits due to competitive entry in the product market.

with no cash flow payoff.

A.3 Financing Choices

The firm has no internal funds available at $t = 0$. Therefore, in order to finance the existing product line and R&D, it raises all the necessary financing by issuing debt and equity at $t = 0$ and $t = 1$, which then determines its capital structure.

Shareholders will be paid off at $t = 2$. In order to raise equity, the firm's initial shareholders, who we treat as insiders, and who have no wealth of their own to invest, must give up ownership $\alpha \in (0, 1)$ in order to raise the necessary capital. At any date ($t = 0$ or $t = 1$), shareholder unanimity is needed to approve a decision to raise capital. Thus, at $t = 0$ this decision is made to maximize the wealth of the insiders (initial owners) plus the value of their non-contractible benefits, B. At $t = 1$, this decision will require those who became shareholders at $t = 0$ to also approve. Those new shareholders are pure investors who do not get any of the non-contractible benefits of R&D enjoyed by insiders, benefits that include knowledge generation, learning, etc.

If the firm issues debt, the face value of debt to be repaid at $t = 2$ is F. The initial debt financing raised is D. Although bondholders cannot distinguish between good firms and lemons at $t = 0$, they receive a noisy signal ϕ at $t = 1$ that indicates whether the firm is good or a lemon. The probability distribution of ϕ is:

$$\Pr(\phi = \text{good} \mid \text{firm is good}) = \Pr(\phi = \text{lemon} \mid \text{firm is a lemon}) = \delta \in (0.5, 1). \tag{9}$$

Upon receiving their signal, the bondholders can choose to wait until $t = 2$ to be paid, or to demand early repayment at $t = 1$ at a cost $c > 0$. If repayment occurs at $t = 1$ the bondholders are paid $F_1 \equiv F[1 + r]^{-1} < F$. In equilibrium, since the firm produces no cash flows at $t = 1$, the firm is liquidated to meet any repayment at $t = 1$ (if this is demanded) because it cannot meet the face value owed to bondholders. This modeling setup for debt parallels that of Calomiris and Kahn (1991). If the firm is a good firm, but is erroneously liquidated at $t = 1$ and the R&D is stopped, then all that can be recovered is the present value of the smallest payoff from the assets in place, $x_L(A)[1+r]^{-1}$, plus any cash on hand, where we discount at the riskless rate because liquidation is analogous to making the asset payoff the minimum in all states. If the firm is a lemon, then only the salvage value of assets in place can be recovered. Let this salvage value be $S \in (0, A)$. The value of the assets recovered in liquidation at $t = 1$ can only be determined after the liquidation is completed. We assume that:

$$\frac{[1-g][1-\delta]S}{g\delta + [1-g][1-\delta]} < c < \frac{[1-g]\delta}{[1-g]\delta + [1-\delta]g}. \tag{10}$$

We will show that (10) is sufficient to ensure that bondholders will liquidate the firm when $\phi =$ lemon, but not when $\phi =$ good. We assume that all debt payments are tax deductible at the corporate tax rate T. For debt to be tax deductible, the face value of the debt issued at $t = 0$ cannot exceed the total amount of financing raised at $t = 0$.[6] The variables D, F, and α will all be endogenously determined.

We will assume henceforth that certain parametric restrictions hold:

$$\delta < \bar{\delta} \in (0.5, 1), \quad B > \bar{B}, \tag{11}$$

where $\bar{\delta}$ is an upper bound and $\bar{B}$ is a lower bound. Thus, (11) implies that the non-contractible benefit of R&D to insiders is sufficiently high. The upper bound on δ means that there is sufficient noise in the bondholders' signal.

[6]This is meant to capture the IRS limit on how much of a firm's financing can count as debt for tax purposes.

A.4 Analysis of the Model

We now present our analysis of the model. Throughout the analysis, we will focus on the good firms, since the lemons will always mimic the strategy of the good firm in equilibrium, and acting otherwise would unambiguously reveal them. Nonetheless, the presence of the lemons is needed for the liquidation strategy of the bondholders to be privately optimal for them in the continuation game.

We begin by presenting preliminary results in which we take as a given A^* and R^*, the investments by the firm in assets in place and R&D, as well as a conjectured face value of debt issued at $t = 0$. We subsequently verify these equilibrium values. Because taxes play no role in the first two results, we set $T = 0$ without loss of generality for now. The equilibrium for these choices and beliefs at $t = 0$ is a perfect Bayesian Nash equilibrium.[7]

Lemma 1: *Fix the optimal values of investments A^* and R^* by the firm in assets in place and R&D, respectively. Suppose the firm issues debt with face value $F = x_L(A^*)$. Then it will be rational (privately optimal) for the bondholders to liquidate the firm at $t = 1$ if their signal is $\phi =$ lemon, and allow it to continue if their signal is $\phi =$ good.*

Proof: Suppose the bondholders' signal at $t = 1$ says $\phi =$ lemon. Let

$$\hat{g}_l = \Pr(\text{firm is good} \mid \phi = \text{lemon}) = \frac{[1-\delta]g}{[1-\delta]g + [1-g]\delta}. \tag{12}$$

For the bondholders to wish to liquidate the firm at $t = 1$, it must be true that:

$$[1-\hat{g}_l]\,S + \hat{g}_l\left[x_L(A^*)\,[1+r]^{-1}\right] - c > \hat{g}_l x_L(A^*)\,[1+r]^{-1}, \tag{13}$$

where the left-hand side of (13) is the expected value of what the bondholders collect at $t = 1$ and the right-hand side is the expected present value of what the bondholders collect

[7] The equilibrium of our focus also satisfies the conditions of sequential equilibrium (Kreps and Wilson (1982)) and the universal divinity refinement of Banks and Sobel (1987); details of the proofs of the characterized outcomes satisfying the universal divinity refinement are available upon request.

if they wait until $t = 2$. We see that (13) simplifies to

$$\left\{ \frac{[1-g]\delta}{[1-\delta]g + [1-g]\delta} \right\} S > c, \tag{14}$$

which we know holds by (10). Now suppose the bondholders' signal at $t = 1$ is $\phi =$ good. Let $\hat{g}$ be the posterior belief of the bondholders that the firm is good after having observed this signal. For the bondholders not to liquidate the firm, we need

$$[1-\hat{g}]\, S + \hat{g}\left[x_L\left(A^*\right)[1+r]^{-1}\right] - c < \hat{g} x_L\left(A^*\right)[1+r]^{-1}, \tag{15}$$

where

$$\hat{g} = \frac{\delta g}{\delta g + [1-\delta][1-g]} < c. \tag{16}$$

Substituting (16) into (15), we see that we need

$$\frac{[1-\delta][1-g]S}{\delta g + [1-\delta][1-g]} < c, \tag{17}$$

which holds by (10). ■

Lemma 2: *Fix the optimal values of investments A^* and R^* by the firm in assets in place and R&D, respectively. Suppose the firm issues debt with face value $F = x_L\left(A^*\right)$. Then, for B large enough, it will prefer to raise at $t = 0$ the present value of the second-stage financing that will be needed at $t = 1$, and hold it as cash (invest it in the riskless asset) rather than wait until $t = 1$ to raise the financing.*

Proof: Given this F, it is clear that in the down state of the economy for the assets in place, (6) implies that the firm will be unable to raise second-stage financing for its R&D at $t = 1$ if the R&D is modestly successful and the expected R&D payoff at $t = 2$ is $y_-\left(R^*\right)$. We will compare the net benefit to the insiders from issuing equity at $t = 0$ to raise $\hat{\omega}R[1+r]^{-1}$ in financing with the net benefit to them of issuing equity at $t = 1$ to raise the necessary financing. Consider first the case of raising financing at $t = 0$, and let $\hat{\alpha} \in (0, 1)$ be the fraction of ownership given up in order to raise $\hat{\omega}R[1 + r]^{-1}$. Thus, the competitive pricing condition implies

$$\hat{\omega}R[1 + r]^{-1} = \hat{\alpha}gV_E, \tag{18}$$

where we define $V_E = [\delta\Omega_0 + [1 - \delta]\hat{\omega}R[1 + r]^{-1}]$ and (suppressing the arguments of functions):

$$\Omega_0 \equiv [1+r]^{-1}\,[q_+y_+ + q_-y_-] + p[1-\theta]\,[x_H - x_L]\,[1+K]^{-2} + [1 - q_+ - q_-]\,\hat{\omega}R[1+r]^{-1}. \tag{19}$$

So V_E is the true value of the good firm's equity at $t = 0$ as assessed by the insiders. Ω_0 can be understood as follows. The first term is the expected present value of the R&D payoff, the second term is present value of assets in place (where we recognize that $F = x_L$), and the third term is the additional R&D financing raised at $t = 0$ that remains idle at $t = 1$ because the R&D fails the first-stage. The market value of this equity is $g\delta V_E$ because the market assesses the probability of the firm being good as g, and δ is the probability that a good firm will be allowed to continue. Note that $1 - \delta$ is the probability that a good firm will be liquidated, in which case $x_L + \hat{\omega}R$ is recovered. Since $F = x_L$, the shareholders only collect $\hat{\omega}R$, with present value $\hat{\omega}R[1 + r]^{-1}$ at $t = 0$. This explains the $[1 - \delta]\,\hat{\omega}R[1 + r]^{-1}$ term in V_E in (18). Thus,

$$\hat{\alpha} = \frac{\hat{\omega}R[1 + r]^{-1}}{gV_E}. \tag{20}$$

The net wealth of the insiders plus the non-contractible benefits from raising extra financing at $t = 0$ is:

$$NW_0 = [1 - \hat{\alpha}]\,V_E + \delta\,[q_+ + q_-]\,B, \tag{21}$$

where $\delta\left[q_{+}+q_{-}\right]$ is the probability that the extra R&D investment will be made at $t=1$ and the R&D will be continued. Thus, substituting (20) into (21):

$$\begin{aligned} NW_0 &= V_E-\hat{\omega}R[1+r]^{-1}g^{-1}+\delta\left[q_{+}+q_{-}\right]B \\ &= \delta\Omega_0-\hat{\omega}R[1+r]^{-1}\left\{g^{-1}-[1-\delta]\right\}+\delta\left[q_{+}+q_{-}\right]B. \end{aligned} \tag{22}$$

Now consider financing at $t=1$. There are two possible states related to the assets in place: the up state and the down state. Moreover, financing will only be raised if: (i) the bondholders' signal $\phi=$ good, and (ii) the R&D has been discovered to be very successful. Given (6) and the need for approval from those who became new shareholders at $t=0$ by purchasing the equity issued by the firm then, it is clear that no financing can be raised at $t=1$ if the R&D is only modestly successful. If $\phi=$ good, the posterior belief of the bondholders about the firm's type becomes

$$\hat{g}=\Pr(\text{firm is good}\mid\phi=\text{good})=\frac{\delta g}{\delta g+[1-\delta][1-g]}. \tag{23}$$

Let α_u be the ownership the firm must surrender at $t=1$ in the up-state to raise $\hat{\omega}R$ then. This means

$$\alpha_u\hat{g}\left\{y_{+}+[x_H-x_L]\right\}[1+r]^{-1}=\hat{\omega}R, \tag{24}$$

which implies that

$$\alpha_u=\frac{\hat{\omega}R}{\hat{g}V_u^1}, \tag{25}$$

where

$$V_u^1\equiv\left\{y_{+}+[x_H-x_L]\right\}[1+r]^{-1}. \tag{26}$$

If α_d is the ownership the firm must surrender at $t=1$ in the down state to raise $\hat{\omega}R$, then

$\alpha_d \hat{g} y_+ [1+r]^{-1} = \hat{\omega} R$, which implies

$$\alpha_d = \frac{\hat{\omega} R}{\hat{g} V_d^1}, \tag{27}$$

where

$$V_d^1 \equiv y_+ [1+r]^{-1}. \tag{28}$$

For the firm's insiders at $t = 0$, their expected wealth from pursuing this strategy is

$$\begin{aligned} \mathbb{E}[NW_1] &= \delta \left\{ q_+ p [1-\theta] [1-\alpha_u] V_u^1 + [1-q_+] [x_H - x_L] [1+r]^{-1} \right\} \\ &\quad + \delta \left\{ q_+ [1 - p[1-\theta]] [1-\alpha_d] V_d^1 + q_+ B \right\}, \end{aligned} \tag{29}$$

where we note that the non-contractible rent B is available to insiders only if the R&D is very successful. Expressing $\hat{V}_u^1$ and $\hat{V}_d^1$ as the date-0 present values of V_u^1 and V_d^1 respectively, we can write

$$\hat{V}_u^1 = \{ y_+ + [x_H - x_L] \} [1+r]^{-2}, \tag{30}$$

$$\hat{V}_d^1 = y_+ [1+r]^{-2}. \tag{31}$$

Simplifying (29) by substituting (25) and (27), we get

$$\begin{aligned} \mathbb{E}[NW_1] &= \delta \left\{ q_+ p [1-\theta] V_u^1 - q_+ p [1-\theta] \hat{\omega} R \hat{g}^{-1} + q_+ [1 - p[1-\theta]] V_d^1 \right\} \\ &\quad + \delta \left\{ -q_+ [1 - p[1-\theta]] \hat{\omega} R \hat{g}^{-1} + q_+ B + [1-q_+] [x_H - x_L] [1+r]^{-1} \right\}. \end{aligned} \tag{32}$$

Simplifying, we can write the present value (at $t = 0$) of $\mathbb{E}[NW_1]$ as:

$$\begin{aligned} \hat{\mathbb{E}}[NW_1] &= \delta \left\{ q_+ p [1-\theta] \hat{V}_u^1 + q_+ [1 - p[1-\theta]] \hat{V}_d^1 \right\} \\ &\quad + \delta \left\{ -q_+ [1+r]^{-1} \hat{\omega} R \hat{g}^{-1} + q_+ B + [1-q_+] [x_H - x_L] [1+r]^{-2} \right\}. \end{aligned} \tag{33}$$

The firm's insiders will prefer to raise the extra R&D financing at $t = 0$ rather than at

$t = 1$ if $NW_0 > \hat{\mathbb{E}}[NW_1]$, where NW_0 is defined in (22). Upon simplification, this condition becomes

$$q_- \left[B + y_-[1+r]^{-2}\right] > \hat{\omega} R[1+r]^{-1} \left\{ \frac{1}{g\delta + [1-\delta][1-g]} - \frac{1-\delta}{\delta} - [1-q_-] \right\}, \tag{34}$$

which holds for B large enough. ■

Let F be the face value of debt if the bondholders wait until $t = 2$ to be repaid, and let F_1 be the face value if they ask to be repaid at $t = 1$. We can now write down the firm's maximization problem, taking as a given that it will raise $R + \hat{\omega} R[1+r]^{-1}$ for its R&D and A for its assets in place through a mix of debt and equity financing at $t = 0$. The value of equity as assessed by insiders at $t = 0$ is similar to the way it was expressed in the proof of Lemma 2:

$$\begin{aligned} V_E \;=\;& [1-T]\delta\big\{[1+r]^{-2}\left[q_+ y_+(R) + q_- y_-(R)\right] + p[1-\theta]\left[x_H(A) - F\right][1+r]^{-2} \\ &+ [1-p[1-\theta]]\left[x_L(A) - F\right][1+r]^{-2} + [1-q_+-q_-]\,\hat{\omega} R[1+r]^{-1}\big\} \\ &+ [1-T][1+r]^{-1}[1-\delta]\max\left\{0, \hat{\omega} R + x_L(A)[1+r]^{-1} - F_1\right\}, \end{aligned} \tag{35}$$

where we recognize that a good firm will be liquidated at $t = 1$ with probability $1-\delta$ by the bondholders, and the value of equity in this case will be equivalent to a call option on the liquidation value of the assets with a strike price equal to what bondholders are owed, F_1.

If α is the fraction of equity surrendered in addition to F, the face value of debt to raise $A + R + \hat{\omega} R[1+r]^{-1}$ at $t = 0$, then α satisfies:

$$\alpha V_E(A^*, R^*) = A^* + R^* + \hat{\omega} R^*[1+r]^{-1} - D, \tag{36}$$

where D is the amount of debt financing raised at $t = 0$. So D satisfies:

$$D = \text{PV}\left\{g\left[\delta\mathbb{E}_2\left[F\right] + [1-\delta]\min\left\{F_1, x_L\left(A^*\right)[1+r]^{-1} + \hat{\omega}R^*\right\}\right] + [1-g]\delta S[1+r]^{-1}\right\}, \tag{37}$$

where PV is the present value operator, and (37) reflects the fact that if the firm is good (probability g), then bondholders allow it to continue with probability δ, yielding an expected payoff at $t = 2$ of $\mathbb{E}_2[F]$ to the bondholders. If the good firm is liquidated, the bondholders receive $\min\{F_1, x_L(A^*)[1+r]^{-1} + \hat{\omega}R^*\}$, while if the bad firm is liquidated, they receive S.

The insiders of the firm choose the investments A and R, and the mix of debt and equity to finance them, by solving the following problem:

$$\max_{(A,R)\in\mathbb{R}^2,\, \alpha\in[0,1],\, F\geq 0} \{[1-\alpha]V_E + \mathbb{E}[B]\}$$
$$\text{subject to (36) and (37).} \tag{38}$$

Here $\mathbb{E}[B]$ is the expected value of the insiders' non-contractible benefits, where the expectation depends on the firm's chosen capital structure.

We now establish a result about the firm's capital structure choice.

Proposition 1: *For any given A^* and R^*, the firm will set $F = x_L(A^*)$, $F_1 = F[1+r]^{-1}$.*

Proof: Suppose counterfactually that $F > x_L(A^*)$. Then we will establish that the bondholders will find it subgame perfect to liquidate the firm at $t = 1$ regardless of ϕ. To see this, suppose $\phi =$ good. Then the bondholders' expected payoff at $t = 1$ if they liquidate the firm is $\hat{g}F + [1-\hat{g}]S$, since $x_L(A^*)[1+r]^{-2} \geq A^*$, so $x_L(A^*)[1+r]^{-1} + \hat{\omega}R^* > A^* + R^*$, given $\hat{\omega} > 1$ and $F < A^* + R^*$. If they allow the firm to continue, then their expected payoff is

$$\hat{g}\left\{x_L\left(A^*\right) + \int_0^{F - x_L(A^*)} \tilde{y}\xi_+ dy\right\}, \tag{39}$$

if the R&D is very successful. Since $F > x_L(A^*)$, it is clear that

$$F > x_L(A^*) + \int_0^{F - x_L(A^*)} \tilde{y}\xi_+ dy, \tag{40}$$

so the bondholders will liquidate the firm. If ϕ = lemon, the bondholders' payoff with liquidation is

$$g_l F + [1 - g_l] S, \tag{41}$$

and the continuation value of the bondholders' payoff is

$$g_l \left\{ x_L(A^*) + \int_0^{F - x_L(A^*)} \tilde{y}\xi_+ dy \right\}. \tag{42}$$

Clearly, the liquidation payoff is higher. Given this, it is not optimal for the insiders at $t = 0$ to set $F > x_L(A^*)$.

Suppose that $F < x_L(A^*)$. Then, given Lemma 1, we know that the firm will be liquidated if ϕ = lemon and allowed to continue if ϕ = good. When $F < x_L(A^*)$, (35) can be written as:

$$\begin{aligned} \hat{V}_E \;=\; & [1-T]\delta\big\{[1+r]^{-2}[q_+y_+ + q_-y_-] + p[1-\theta][x_H(A) - F][1+r]^{-2} \\ & + [1 - p[1-\theta]][x_L(A) - F][1+K]^{-2} + [1 - q_+ - q_-]\hat{\omega}R[1+r]^{-1}\big\} \\ & + [1-T][1+r]^{-1}[1-\delta]\left[\hat{\omega}R + x_L(A)[1+r]^{-1} - F_1\right]. \end{aligned} \tag{43}$$

Thus, the total value of the insiders' claim plus non-contractible benefits is:

$$[1-\alpha]\hat{V}_E + [q_+ + q_-] B, \tag{44}$$

where

$$\alpha = \frac{A + R[1+\omega] - D}{g\hat{V}_E}, \tag{45}$$

$$\omega \equiv \hat{\omega}[1+r]^{-1}, \tag{46}$$

and using (37), we can write

$$D = gF[1+r]^{-2} + [1-g]\delta S[1+r]^{-1}, \tag{47}$$

where we recognize that if the firm is good, then the bondholders receive either $F_1 = F[1+r]^{-1}$ at $t = 1$, or F at $t = 2$, so this payoff is riskless and has present value $F[1+r]^{-2}$ at $t = 0$. If the firm is a lemon and the bondholders liquidate at $t = 1$ (joint probability $[1-g]\delta$), then their payoff is S, with present value $S[1+r]^{-1}$. Substituting (45) and (47) into (43) yields the insiders' objective function:

$$\begin{aligned}
\Omega &= \hat{V}_E - \alpha\hat{V}_E + [q_+ + q_-]\,B \\
&= \hat{V}_E - \frac{\{A + R[1+\omega] - gF[1+r]^{-2} - [1-g]\delta S[1+r]^{-1}\}}{g} + [q_+ + q_-]\,B \\
&= \hat{V}_E - \frac{\{A + R[1+\omega] - [1-g]\delta S[1+r]^{-1}\}}{g} + F[1+r]^{-2} + [q_+ + q_-]\,B
\end{aligned} \tag{48}$$

Thus,

$$\frac{\partial \Omega}{\partial F} = -[1-T]\delta[1+K]^{-2} + [1+r]^{-2} > 0. \tag{49}$$

Thus, the firm will wish to increase F when $F < x_L(A^*)$. Since $F > x_L(A^*)$ has been ruled out, it must be true that $F = x_L(A^*)$. ■

We next examine how the firm determines A^* and R^*, taking the capital structure choice just derived as given. That is, the firm solves:

$$(A, R) \in \arg\max_{\mathbb{R}^2} \Omega, \tag{50}$$

with $A + R = I$. The following result can now be proved.

Proposition 2: *At $t = 0$, There is a unique optimal level of investment in assets in place,*

A^*, *and a unique optimal level of investment in R&D,* R^*, *with* $\partial A^*/d\theta < 0$ *and* $\partial R^*/d\theta > 0$.

Proof: The first-order condition that A^* satisfies is $\partial\Omega/\partial A = 0$. Recognizing that $A+R = I$ and using (43) for $\hat{V}_E$, we can write the first-order condition as

$$[1-T]\delta\left\{[1+r]^{-2}\left[\left[\frac{\partial y_+}{\partial R}\right]\left[\frac{\partial R}{\partial A}\right]q_+ + \left[\frac{\partial y_-}{\partial R}\right]\left[\frac{\partial R}{\partial A}\right]q_-\right] + p[1-\theta]\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right][1+r]^{-2}\right.$$
$$\left. + [1-q_+-q_-]\,\omega\left[\frac{\partial R}{\partial A}\right]\right\} + [1-T][1-\delta]\omega\left[\frac{\partial R}{\partial A}\right] - \frac{1+\left[\frac{\partial R}{\partial A}\right][1+\omega]}{g} = 0 \tag{51}$$

Since $\partial R/\partial A = -1$, we can write (51) as:

$$[1-T]\delta\left\{-[1+r]^{-2}\left[q_+\left[\frac{\partial y_+}{\partial R}\right] + q_-\left[\frac{\partial y_-}{\partial R}\right]\right] + p[1-\theta]\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right][1+r]^{-2} - [1-q_+-q_-]\,\omega\right\}$$
$$-[1-T][1-\delta]\omega - \omega g^{-1} = 0 \tag{52}$$

The second-order condition for a unique maximum is $\partial^2\Omega/\partial A^2 < 0$, which translates to

$$[1-T]\delta[1+r]^{-2}p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2} - \frac{\partial^2 x_L}{\partial A^2}\right] < 0, \tag{53}$$

given (1). To show that $dA^*/d\theta < 0$, we totally differentiate the first-order condition (51):

$$[1-T]\delta[1+r]^{-2}\left\{-p\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right] + p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2} - \frac{\partial^2 x_L}{\partial A^2}\right]\left[\frac{dA^*}{d\theta}\right]\right\} = 0, \tag{54}$$

which yields

$$\frac{dA^*}{d\theta} = \frac{p\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right]}{p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2} - \frac{\partial^2 x_L}{\partial A^2}\right]} < 0, \tag{55}$$

since by (1), $\partial x_H/\partial A > \partial x_L/\partial A$ and $\partial^2 x_H/\partial A^2 - \partial^2 x_L/\partial A^2 < 0$. The result that $dR^*/d\theta > 0$ follows from the fact that $\partial R/\partial A = -1$. Thus, since $dA^*/d\theta < 0$, it follows that $dR^*/d\theta > 0$.

■

This proposition shows that as competition increases, the firm invests more in R&D and less in assets in place that are used to support and expand existing products. The economic intuition is that investing in coming up with proprietary new products/knowledge becomes more valuable *relative to* investing more in the existing business as competition compresses margins in existing products, but the output of R&D is patent-protected.

We now examine how competition affects the firm's debt and cash positions.

Proposition 3: *An increase in competition will reduce the debt issued by the firm and increase the cash carried.*

Proof: As shown in Proposition 2, $\partial A^*/d\theta < 0$, so an increase in competition θ reduces the amount invested in assets in place. Since $F = x_L(A^*)$ and $\partial x_L/\partial A > 0$ from (1), it follows that a smaller A^* means a lower F, and hence less debt. In terms of the response of cash reserves to competition, Lemma 2 shows that the firm will prefer to raise all of the financing that it anticipates in the future at $t = 0$, and hold it as cash. The amount that the firm holds as cash for the future R&D investment is ωR. Therefore, since $\partial R^*/d\theta > 0$ from Proposition 2, an increase in competition θ increases the amount invested in R&D and hence the amount of cash that the firm holds at $t = 0$. ■

The intuition behind this proposition is that an increase in competition will induce the firm to reduce its investment in assets in place, which in turn reduces the amount of debt that the firm can carry, since the face value is set to the lowest payout from the assets in place. Put differently, an increase in competition will reduce the collateral base of the firm that supports debt by reducing investment in assets in place. The firm holds additional cash in response to competition due to a precautionary demand for liquidity, since it may not be able to raise enough financing in some states in the future. As the relative attractiveness of R&D goes up due to higher competition, so does the excess cash the firm carries to meet future liquidity demand. These two results also imply that net debt (defined as debt minus cash) will decline as competition increases.

References

[1] Banks, Jeffrey S., and Joel Sobel. "Equilibrium selection in signaling games." *Econometrica: Journal of the Econometric Society* (1987): 647-661.

[2] Calomiris, Charles W., and Charles M. Kahn. "The role of demandable debt in structuring optimal banking arrangements." *The American Economic Review* (1991): 497-513.

[3] Gans, Joshua S., and Scott Stern. "Incumbency and R&D incentives: Licensing the Gale of Creative Destruction." *Journal of Economics & Management Strategy* 9, no. 4 (2000): 485-511.

[4] Kreps, David M., and Robert Wilson. "Reputation and imperfect information." *Journal of Economic Theory* 27, no. 2 (1982): 253-279.