On the Impossibility of Efficient Investment in Innovation

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Abstract

I show that in the environment of imperfect information and costly learning, competitive investors overinvest in innovation, compared to a social optimum of maximized profits. I also show that in competitive markets, it is generally impossible to design a mechanism that implements a socially optimal level of investment in innovation as a Nash equilibrium of a noncooperative game. I argue that contractual provisions that restrain the entry of new investors, while ensuring the exit of existing investors can mitigate the problem of overinvestment in innovation. The argument is supported by the presence in venture capital contracts such restraining provisions as pre-emptive rights, approval rights, rights of first refusal, antidilution protection, demand rights, and exit rights.

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1 Introduction

There is a widespread belief that investment in innovation suffers from irrational investor behavior. For example, in his keynote address to the SUPERCOMM 2002 Conference, Craig R. Barrett, the Chief Executive Officer of Intel Corporation said:

"Every time a new technological innovation has come forward, there's been the same sort of reception of that technology and the same sort of trend during its growth. If you go back and look at canal building in Western Europe in the 1700s, if you look at the advent of the steam locomotive and the growth of the railroad industry, if you look at the growth of the steel industry, if you look at the electrification of the United States and the rest of the world, look at the automobile industry, they all have the same trend. The technology gets introduced, there's a rapid growth and acceptance of the technology, there's ... irrational exuberance, there's over investment of capital, there's an over inflation of stock price, there's an excess number of competitors in the industry."

Yet, if a multitude of unrelated investors consistently display such behavior across time and space, it is reasonable to examine similarities in their investment environment before assuming that they all share a common irrational trait.

In this paper I show that overinvestment in innovation arises as a result of rational decisions made by competitive investors. In an environment characterized by imperfect information and costly learning, rational competitive investors continue investing in risky innovative projects for too long, compared with a social optimum of maximized profits.

I present a model, in which a wealth-constrained innovator approaches a competitive investor with a proposal to finance her risky project. Information about both the quality of the project and the project's success is imperfect. Initially, with certain probability, the project is either "good" or "bad". If the project is good, then with some probability it exits successfully in the current period and starts paying a steady flow of benefits over the infinite time horizon. If the project is bad, then the probability of a successful exit is zero.

In order to learn about the quality of the project and maintain the possibility of a successful exit, the investor must continue injecting funds into the project. Financing facilitates Bayesian learning: if the project has not successfully exited in the current period, then it is less likely to be considered good in the next period. The investor can stop financing the projects at any time. The parties can also renegotiate the original arrangement at no cost. Moreover, the parties cannot agree not to renegotiate. In particular, an investor cannot commit to refuse funding a project with positive expected profits.

I show that rational competitive investors overinvest in innovation. From the social welfare perspective, it is optimal to stop financing any project that has not exited at the point of maximum expected profits. Even if a project turns out to be good, the resources could have earned higher returns elsewhere in the economy (at zero profits to the investor).

However, doing so would require stopping some projects when their expected profits are still positive. This contradicts the objective function of a competitive investor. Thus, competition among rational investors leads to a waste of resources.

Can the investor and innovator negotiate their way to efficiency? I show that in the environment of imperfect information and costly learning, the answer is generally negative. I argue that in competitive markets, it is generally impossible to design a mechanism (e.g., a contract) that implements a socially optimal level of investment in innovation as a Nash equilibrium of a noncooperative game. I prove that the socially optimal investment rule is not Maskin monotonic. Maskin monotonicity deals not only with the efficiency of a particular choice, but also with the contribution of each agent needed to achieve that choice as an efficient outcome and, thus, accounts for incentives to innovate and invest. Intuitively, while the project still has a positive expected payoff that attracts competition, it is generally impossible for the parties to stop at a socially optimal investment level.

Can the parties get "close" to the optimal outcome? I argue that the impossibility result may be circumvented for a modified choice rule. Without the loss of generality, I construct a monotonic choice rule that implements outcomes ϵ-close to those selected by the socially optimal rule, where ϵ depends on the number of investors allowed to finance the project.

How can an efficiency-enhancing mechanism be designed in practice? In this paper, I focus on efficiency-enhancing contractual provisions between investors and innovators. I argue that contractual provisions that restrain the entry of new investors, while ensuring the exit of existing investors can mitigate the problem of overinvestment in innovation.[1] Welfare-enhancing effects explain why rational innovators willingly agree to such restraining provisions in venture capital contracts as pre-emptive rights, approval rights, rights of first refusal, antidilution protection, demand rights, and exit rights.

The rest of the paper is organized as follows. Section 2 contains a discussion on the paper's contribution to the existing literature. The model is presented in Section 3. The analysis of overinvestment in innovation is in Section 4. The impossibility argument is in Section 5. The modified choice rule is described in Section 6. Conjectures about efficiency-enhancing mechanisms and evidence from venture capital contracts are in Section 7. Section 8 concludes the paper.

2 Contribution

This paper contributes to a large body of research on investment in invention and innovation. Earlier research shows that competition among potential innovators leads to premature

[1] There may exist other ways to design such an efficiency-enhancing mechanism. For example, legal and regulatory provisions on investment in innovation (e.g., taxes and licenses) or organizational structures of innovative firms (e.g., open source).

financing of innovative projects.[2] If knowledge is a free public good, an innovator makes discovery available for financing not when the expected profits are maximal, which is socially optimal, but as soon as the expected profits are nonnegative.

The first contribution of this paper is an argument that rather than starting prematurely, investment in innovative projects does not stop early enough. While in both cases this leads to overinvestment, differences in the nature of the underlying problem call for radically different solutions.[3]

The second contribution is the impossibility argument. I argue that it is generally impossible to design a competitive market mechanism that implements a socially optimal level of investment in innovation as a Nash equilibrium of a noncooperative game. The impossibility argument changes the focus of an earlier debate on the optimal market structure for investment in innovation.[4]

There are two opposing views in this debate. Schumpeter (1942) states that monopolies can achieve a socially optimal level of investment in innovation. In contrast, Arrow (1962) argues that incentives for innovation are better under competitive than monopolistic conditions (but still below the socially optimal level).[5]

The impossibility argument supports the notion that competitive markets are not the perfect way to finance innovation. However, it does not automatically lead to either Schumpeter's or Arrow's prescriptions. Earlier studies argue that in order to reduce a premature use of resources, which could have earned higher returns elsewhere, it is optimal to grant monopoly intellectual property rights (e.g. patents) to innovators prior to (and independently of) investment in innovative projects. However, while allocating monopoly rights to intellectual property could solve the problem of starting to invest too early, it fails to protect the financiers from the pressure to continue investing for too long.

Finally, the paper makes a contribution to the literature on contract design. I argue that under imperfect information and costly learning, rational agents can bargain away from inefficiency by imposing voluntary restrains on the number of investors in risky innovative projects.[6] The purpose of such restrains is to protect investors who have already invested in

[2] See, for example, Nelson (1959) and Barzel (1968). See also Tarasyev and Watanabe (2000) for a dynamic model of investment in innovation under perfect information.

[3] An argument that competitive markets overinvest in innovation is not new. For example, Lee and Wilde (1980) argue that if investment in innovation includes a flow cost, competitive investors overspend on R&D. Dasgupta and Stiglitz (1980) also find that "the market economy may be characterized by excessive expenditure on R&D".

[4] See Demsetz (1969), Kamien and Schwartz (1970, 1975) and Baldwin and Scott (1987).

[5] Both Schumpeter (1942) and Arrow (1962) assume that information is a free public good.

[6] Lee and Wilde (1980) also show that as the number of competitive investors increases, the overinvestment in innovation gets worse. However, Delbono and Denicolo (1991) argue that results of the specific model of Lee and Wilde (1980) depend on the assumption of Bertrand (price) competition. Under the assumption of Cournot (quantity) competition, for some parameter values, the increase in the number of competitive investors leads to underinvestment.

the project from outside competition.

I conjecture that contractual provisions that restrain entry of new investors, while ensuring exit of existing investors can mitigate the problem of overinvestment in innovation. Efficiency-enhancing provisions protect investors from competition at the point of entry, continuation, and exit from the project. The conjecture is supported by such typical provisions in venture capital contracts as pre-emptive rights, approval rights, rights of first refusal, demand rights, and exit rights.

3 Model

Consider an economy populated by two types of agents: investors and innovators. In period zero, a wealth-constrained innovator approaches a competitive investor with a proposal to finance a risky project.

3.1 Preferences

Let $A \subseteq \Re^2_+$ be a set of possible outcomes consisting of pairs of expected payoffs to investors and innovators, respectively. Define by R_i, the preferences of investors ($i = 1$) and innovators ($i = 2$) over A. Without the loss of generality, preferences represent attitudes toward project-specific risk. I assume that the binary relation R_i, $i = 1, 2$ is complete and transitive. Notation aR_ib means that agent i weakly prefers outcome a to outcome b. The notation $R = \{R_1, R_2\}$ specifies a preference profile.

3.2 Project

The project promises to pay a steady flow of benefits that grow deterministically at rate p over the infinite time horizon, starting from the initial level, D_0.[7] While the payoff dynamics is known with certainty, information about both the quality of the project and its success is imperfect. Initially, the project is "good" with probability α_0 and "bad" otherwise.[8] If the project is good, then with probability $\lambda < 1$, it exits successfully in the current period. Successful exit is defined as the time when the project starts paying the flow of benefits.[9] If the project is bad, the probability of a successful exit is zero.

I assume that an investor has an alternative of investing free of project-specific risk elsewhere in the economy. The instantaneous risk-free rate of return is denoted by r.

[7] Exponential payoff growth is a simplifying assumption. Typically, aggregate demand for innovative products follows a logistic (S-shaped) function. See, for example, Griliches (1957) and Dixon (1980).

[8] The description of the stochastic process and learning follows Bergemann and Hege (1998, 2001).

[9] In practice, there are several ways to exit a project successfully (Cumming and MacIntosh, 2001). For simplicity, I do not differentiate among the types of successful exits.

3.3 Learning

In this economy, the acquisition of project-specific information is costly. I assume that in order to learn about the quality of the project at time t and maintain the possibility of a successful exit, an investor must inject the amount of financing equal to I_t. The investor can stop financing the risky project at any time.

The financing of the project facilitates Bayesian learning. The posterior probability of the project being "good" satisfies the following logistic differential equation,

$$\frac{d\alpha_t}{dt} = -\lambda\alpha_t (1 - \alpha_t). \tag{1}$$

According to Equation (1), if the project has not successfully exited in period t, then it is less likely to be considered good in the next instance. For $\alpha_t \leq \frac{1}{2}$, learning about the quality of the project is fast as the probability of the project being good decays exponentially at the rate λ. After α_t exceeds $\frac{1}{2}$, the decay becomes logarithmic and additional funding contributes progressively less to learning about the quality of the project.

The solution to Equation (1) is given by,

$$\alpha_t = \frac{\alpha_0}{(1 - \alpha_0) e^{\lambda t} + \alpha_0}, \tag{2}$$

where the initial probability, α_0, is project-specific (e.g., the quality of the management team), while λ, the probability of a successful exit is exogenously determined by economy-wide conditions (e.g., conditions in the IPO market).

3.4 Information

Define by S_t, $t = 0, 1, ...$, time-specific information about the project available at an instant t. In general, this information includes the posterior probability of the project being "good", α_t, the amount of financing injected up to and including instant t, I_t, and a (possibly time-varying) rate at which the financing is injected.

For simplicity, I assume that the necessary investment level is equal to λI_0, where I_0 is a known total investment level. I also assume that the funds must be injected at a constant rate λ. Together these assumptions imply,

$$I_t = \lambda I_0 \int_0^t e^{\lambda s} ds. \tag{3}$$

Thus, in this economy, the set $S_t = \{\alpha_t, I_t\}$, where both variables are deterministic functions of t.

4 Investment in innovation

In this section I argue that if financial resources must be spent in order to continue learning about an innovative project, competitive investors continue investing for too long, compared with a social optimum of maximized profits.

The expected net present value of a risky project that successfully exits at time t, $\tilde{V}_{0t}$, is equal to

$$\tilde{V}_{0t} = \alpha_t \lambda \int_t^{\infty} D_0 e^{-(r-p)\tau} d\tau - \lambda I_0 e^{-rt} \int_0^t e^{\lambda s} ds. \tag{4}$$

The first term of the difference is the discounted revenue stream of a project that successfully exited at time t times the probability of a successful exit, λ, and the probability of a project being good at time t, α_t. The second term is the discounted cost of injecting λI_0 at rate λ up to time t.

For $0 < p < r$, the problem (4) can be re-written as

$$\tilde{V}_{0t} = \frac{\alpha_t \lambda D_0 e^{-(r-p)t}}{r-p} - I_0 \left(e^{-(r-\lambda)t} - e^{-rt} \right). \tag{5}$$

Zero profit condition is given by

$$\frac{\alpha_0 \lambda D_0 e^{pt}}{(1-\alpha_0) e^{\lambda t} + \alpha_0} = (r-p) I_0 \left(e^{\lambda t} - 1 \right) \tag{6}$$

and the first-order optimality condition is given by

$$\frac{\lambda^2 \alpha_0 (1-\alpha_0) e^{\lambda t} D_0 e^{pt}}{((1-\alpha_0) e^{\lambda t} + \alpha_0)^2 (r-p)} + \frac{\alpha_0 \lambda D_0 e^{pt}}{(1-\alpha_0) e^{\lambda t} + \alpha_0} = r I_0 \left(e^{\lambda t} - 1 \right) - \lambda I_0 e^{\lambda t}. \tag{7}$$

Note that investment level is a deterministic function of t. Denote by $\hat{t}$ and $t^{\star}$, the values of t that solve Equations (6) (zero profit) and (7) (maximum profit), respectively.

Consider the following proposition.

Proposition 1 Competitive investors continue investing for too long, compared with a social optimum of maximized profits.

The objective is to show that for a wide range of parameter values, $t^{\star} < \hat{t}$. The proof is as follows. Observe that Equation (7) can be re-written as

$$A(t) + B(t) + C + \frac{\alpha_0 \lambda D_0 e^{pt}}{(1-\alpha_0) e^{\lambda t} + \alpha_0} = (r-p) I_0 \left(e^{\lambda t} - 1 \right), \tag{8}$$

where for $0 < p \leq \lambda < r$, $A(t)$ and $B(t)$ are positive increasing functions of t and C is a positive constant given by

$$A(t) = \frac{\lambda^2 \alpha_0 (1-\alpha_0) e^{\lambda t} D_0 e^{pt}}{((1-\alpha_0) e^{\lambda t} + \alpha_0)^2 (r-p)}, \tag{9}$$

$$B(t) = (\lambda - p) I_0 e^{\lambda t}, \tag{10}$$

and

$$C = pI_0. \tag{11}$$

Observe also that right hand sides of Equations (6) and (8) are identical, while the left hand side of Equation (8) is strictly greater than the left hand side of Equation (6) for all t. Since the term t enters only as a power of the exponential function, all time-dependent components of Equations (6) and (8) are strictly convex functions of time. Therefore, $t^\star$ that solves (8) must come strictly earlier than $\hat{t}$, the solution to (6).[10] This result also holds for some values of $\lambda < p$, as long as $A(t) + B(t) + C > 0$ for all t. This competes the proof.

4.1 Incomplete information, competition, and other considerations

In this paper I abstract from a number of potentially important aspects of investment in innovation due to either a lack of consensus or mixed empirical evidence.

I abstract from the agency aspects of financing. I assume that the disbursed funds are fully invested into the project and that both parties value only pecuniary benefits of the project. I conjecture that incomplete information makes overinvestment worse. If the investor knows (but cannot verify) that only a fraction $0 \leq \theta < 1$ of his funds is devoted to the project, then he changes the equation for the posterior probability to

$$\frac{d\alpha_t}{dt} = -\theta \lambda \alpha_t (1 - \alpha_t). \tag{12}$$

[10] In the case without learning (e.g. Barzel (1968)), Equation (8) can be re-written as $C + D_0 e^{pt} = rI_0$. In this case, the reverse is true: "zero-profit" time comes sooner than the optimal time.

Because the innovator diverts some of the funds, additional funds need to be injected in order to continue learning about the quality of the project and maintain the possibility of a successful exit. A competitive investor is willing to pay the rent to the innovator as long as the expected profits remain nonnegative.

If the investor does not observe the size of the rent appropriated by the innovator, then he (the investor) can use control type restrictions to screen innovators and optimize the amount of diverted funds. The parties negotiate an optimal allocation of control rights that ensures nonnegative expected profits for the investor and private benefits for the innovator.[11] The outcome is essentially the same as if the investor had observed the size of the rent.

However, Bergemann and Hege (1998) offer an alternative conclusion. They assume that the investor forms his posterior probability believing that the innovator puts all allocated funds into the project. As a result, the investor underestimates the posterior probability of success and stops investing earlier than in the competitive case.

I also abstract from the aspects of competition in the product market. I assume that once the innovative project has successfully exited, payoffs to the original investor(s) and innovator grow deterministically over the infinite time horizon.

There is a large industrial organization literature on the relationship between competition in the product market and incentives to innovate.[12] The main theoretical argument of this literature is that product market competition reduces incentives to invest in innovation by limiting profits from innovative projects.[13] Thus, product market competition limits overinvestment in innovation.

However, the original theoretical argument about the negative relationship between product market competition and innovation has not been widely supported empirically. Nickell (1996) and Blundell, Griffith, and Van Reenen (1999) show a positive correlation between product market competition and innovative output. Recently, Aghion, Bloom, Blundell, Griffith, and Howitt (2002) show that a negative relationship between competition and innovation predicted by theory holds only for high initial levels of product market competition. At low initial levels of product market competition, competition induces innovation.

5 Impossibility of Efficient Investment in Innovation

In the previous section I proved in the context of a specific model that competitive investors continue investing for too long, compared with a social optimum of maximized profits. In this section I argue that it is generally impossible to design a mechanism that implements a socially optimal level of investment in innovation as a Nash equilibrium of a noncooperative game.

[11] See, Kirilenko (2001) for the analysis of control rights in risky projects.

[12] See, Nickell (1996) and Aghion, Bloom, Blundell, Griffith, and Howitt (2002) for references.

[13] Klette and Griliches (1999) attribute this argument to Schumpeter (1942).

5.1 Definitions

Define as $F : R \to A$, a mapping from preference profiles into outcomes such that for any R, $F(R)$ represents a set of socially optimal outcomes at profile R. I assume that F is a social choice rule that selects maximum-profit allocations for any profile of preferences.

Define as $G : R \to A$, another mapping from preference profiles into outcomes such that for any R, $G(R)$ represents a set of competitive market outcomes at profile R. I assume that G is a choice rule that selects individually rational allocations that satisfy nonnegative expected profits condition.

Denote by $E : R \times S_t \to \Sigma$, a mapping from preference profiles and available information, S_t, $t = 0, 1, ...$ into strategies, $\Sigma = \sigma_1 \times \sigma_2$. Define as $M : \Sigma \to A$ a mapping from strategies into outcomes such that for any $\sigma \in \Sigma$, $M(\sigma)$ represents a set of equilibrium outcomes determined by mechanism M.

Restrictions on Σ represent behavioral rules that define equilibria in the economy. Let $(\sigma_{-i}, \bar{\sigma}_i)$ denote a strategy profile $\sigma \in \Sigma$, where the ith element is replaced with some other strategy $\bar{\sigma}_i \in \Sigma$.

For a given (Σ, M, R), a pure strategy Nash equilibrium is a set of strategies, $\sigma \in \Sigma$ such that $M(\sigma) R_i M(\sigma_{-i}, \bar{\sigma}_i)$ for all i and $\bar{\sigma} \in \Sigma$.

5.2 Maskin Monotonicity and Nash Implementation

We would like to know if there exists a mechanism that implements a socially optimal investment level as a Nash equilibrium of some noncooperative two-agent game.[14] Maskin (1999) shows that if a social choice rule is Nash implementable, then it must satisfy a condition defined as Maskin monotonicity. Maskin monotonicity is a restrictive condition. It deals not only with the efficiency of a particular choice, but also with the contribution of each agent needed to achieve that choice as an efficient outcome and, thus, accounts for incentives to innovate and invest.

Formally, a choice rule is (Maskin) monotonic if for all $R', R'' \in R$ and $a \in A$, $a \in F(R'')$ whenever (i) $a \in F(R')$, and (ii) for all $b \in A$ and $i = 1, 2$, $aR'_i b$ implies $aR''_i b$.

Intuitively, the monotonicity condition states that if an equilibrium alternative does not fall in preferences of any agent, then it must remain in the set selected by the choice rule.

This condition can be used to check whether the socially optimal choice rule, F, is monotonic. Consider the following proposition.

Proposition 2 Social choice rule $F(R)$ is not monotonic and, thus, cannot be Nash implemented.

[14] This is a standard problem in implementation theory. See Jackson (2001), Maskin and Sjostrom (2001) for recent surveys.

The proof is as follows. Let $\Delta : S_t \rightarrow [0,1]$ be a mapping that gives the share of the expected final payoff for the investor, $\tilde{V_{0t}}$ (as defined in Equation (4)) for all S_t, $t = 0, 1, ...$ Then, for any $\delta \in \Delta$, an outcome $a \in A$ is a pair $\delta \tilde{V_{0t}}, (1-\delta) \tilde{V_{0t}}$.

Consider a preference profile $R' \in R$. The socially optimal choice rule, F, selects an outcome $(x_1, x_2) = F(R')$ if $x_1 + x_2 \geq y_1 + y_2$ for all $(x_1, x_2), (y_1, y_2) \in A$. Since $\tilde{V_{0t}}$ is a strictly decreasing function, the socially optimal outcome is unique.

Consider another preference profile $R'' \in R$ and an outcome $(z_1, z_2) \in A$ such that for some $(y_1, y_2) \in A$, $z_1 > y_1$, $z_2 = y_2$. Moreover, suppose that $z_1 + z_2 > x_1 + x_2$. In other words, under the new profile, R'', the investor values the outcome z more than under the old profile, R', while the preference ordering of the innovator is unchanged. For example, under R'', the investor is less risk averse than under R'. Importantly, after the change, the sum of components of the new outcome, z is greater than that of the original social choice, x. Under this transformation, the equilibrium alternative, (x_1, x_2) does not fall in the preference ordering of either agent. However, the rule F selects z as the new unique outcome. Thus, F is not monotonic. This completes the proof.

Intuitively, for a general set of preferences toward risk, there does not exist a mechanism that implements a socially optimal investment level as a Nash equilibrium of a noncooperative game. Competitive investors are unable to terminate the project when the expected value of the payoff drops below a socially optimal outcome, but remains positive. They take on too much idiosyncratic, project-specific risk compared to a social optimum.

The impossibility result may be circumvented on a restricted set of preferences (attitudes toward project-specific risk) and behavioral rules (equilibrium concepts).[15] For example, if the attitude toward risk can be described by one parameter, the lower bound for this parameter could be set such that competitive investors stop investing at the socially optimal time. Similarly, instead of Nash equilibria, we can consider subgame perfect or other refined equilibrium notions that rule out undesirable outcomes and permit the implementation of desirable ones.[16]

Alternatively, it is possible to keep the preferences and the equilibrium concept general (weak) and modify the choice rule.

6 Modified Choice Rule

In this section I argue that it is possible to design an monotonic choice rule that chooses allocations ϵ-close to those selected by the socially optimal rule, F for some $\epsilon \in \Re^2_+$.

I begin by showing that the competitive choice rule is monotonic. Consider the following proposition.

[15] See, for example, Moore and Repullo (1990) and Dutta and Sen (1991).

[16] See, for example, Moore and Repullo (1988).

Proposition 3 Competitive choice rule $G(R)$ is monotonic.

The proof is as follows. Consider a preference profile $R' \in R$. The competitive choice rule G selects an outcome $(x_1, x_2) = G(R')$ if $x_1 \geq y_1$ for all $(x_1, x_2), (y_1, y_2) \in A$. In other words, the competitive choice rule looks only at how much a competitive investor is willing to contribute toward achieving an outcome. Under the rule G, if the preference profile changes to some $R'' \in R$ such that a previously optimal outcome, say (x_1, x_2), does not move down in preference ordering of either party, the investor will continue selecting the outcome under the new preference profile. If not, then the outcome was not optimal to begin with. This completes the proof.

Intuitively, the main reason why the competitive rule is monotonic while the maximum profit rule is not is that the former coincides with the preferences of the investor alone, while the latter selects an outcome with the highest sum of both agents rankings. Since the agents are dividing up the same expected benefits, it is impossible for them to terminate the project when the expected value of the payoff drops below a socially optimal outcome. If the socially optimal investment rule is monotonic, then investment must stop flowing into the project as soon as expected profits start decreasing. In contrast, a competitive rule coincides with the preferences of a competitive investor who wishes to continue investing until expected profits reach zero.

Construct a social choice rule that is ϵ-close to F by taking a combination of G and F. Define as $H : R \to A$ a mapping from preference profiles into outcomes such that for any R, $H(R)$ represents a set of outcomes such that for all $R' \in R$, $(a_1, a_2) \in F(R')$ implies $(a_1 + \epsilon_1, a_2 + \epsilon_2) \in H(R')$, for some $(\epsilon_1, \epsilon_2) \in \Re^2_+$.

Without the loss of generality, let (ϵ_1, ϵ_2) be a function of the number of small competitive investors $N = 1, 2, ...$ such that for all $R' \in R$, $(b_1, b_2) \in G(R')$,

$$\epsilon_i = \epsilon_i(N) = \left(1 - \frac{1}{N}\right)(b_i - a_i), \qquad i = 1, 2. \tag{13}$$

By construction, when N equals one, $H(R)$ converges to (nonmonotonic) $F(R)$ and as N increases, $H(R)$ converges to (monotonic) $G(R)$.

Define ϵ-restricted entry condition as the number of investors, N such that for all $R' \in R$, $H(R')$ is ϵ-close to $F(R')$. Consider the following proposition,

Proposition 4 For some $\bar{N} < \infty$, $\epsilon\left(\bar{N}\right) \in \Re^2$, there exists an $\epsilon\left(\bar{N}\right)$-close to $F(R)$ choice rule, $H(R)$, which is Nash monotonic and, thus, Nash implementable.

The proof is as follows. Consider a preference profile $R' \in R$. The modified rule H selects an outcome $(x_1, x_2) = H(R)$ if $x_1 + \frac{1}{N}x_2 > y_1 + \frac{1}{N}y_2$ for all $(x_1, x_2), (y_1, y_2) \in A$, $N = 1, 2, ...$

Consider another preference profile $R'' \in R$ and an outcome $(z_1, z_2) \in A$ such that for some $(y_1, y_2) \in A$, $z_1 > y_1$, $z_2 = y_2$. Moreover, suppose that $z_1 + z_2 > x_1 + x_2$. Under this transformation, the equilibrium alternative, (x_1, x_2) does not fall in the preference ordering of either agent.

Choose N such that $z_1 < x_1 + \frac{1}{N}(x_2 - z_2)$. For $N = \infty$, if this condition is not satisfied, z_1 must be greater than x_1, which contradicts the notion that x is a Nash equilibrium. For $z_1 - y_1 < \infty$, continue increasing N, until the amount $z_1 < x_1 + \frac{1}{N}x_2 - \frac{1}{N}y_2$. When this inequality is satisfied, H continues selecting x as an outcome and, thus, is monotonic.

For any $(x_1, x_2), (z_1, z_2) \in A$, define

$$\bar{N} = min\left\{N \mid z_1 < x_1 + \frac{1}{N}(x_2 - z_2)\right\}. \tag{14}$$

For $N = \bar{N}$ and a corresponding value of $\epsilon\left(\bar{N}\right)$, for all $R' \in R$, $H(R')$ is ϵ-close to $F(R')$. This completes the proof.

Note that the efficiency-enhancing rule is fragile. Because the design of the rule assumes a symmetric (albeit imperfect) knowledge of the project's expected payoff, it is not robust with respect to informational assumptions. If the day-to-day management of the project is delegated to the innovator, there is an incentive to conceal the true extend of the expected profits. In addition, such a rule is not robust with respect to renegotiation. Because the innovator is always worse off under the modified rule compared to the competitive rule, there are strong incentives to renegotiate the terms of the original agreement.

7 Efficiency-enhancing mechanisms

In this section I conjecture the properties of efficiency-enhancing mechanisms designed in the form of contractual provisions. I argue that based on the properties of the modified choice rule, efficiency-enhancing contractual provisions should include restrictions on the number of investors in the project. The innovator must be discouraged (but not prohibited) from approaching multiple competitive investors. In addition, at any time, investors must voluntarily agree to participate in the financing of the project. Finally, the mechanism must be (weakly) renegotiation-proof.

7.1 Intellectual Property Rights or Contract Rights?

Earlier studies argue that in order to reduce a premature use of resources, which could have earned higher returns elsewhere, it is optimal to grant monopoly intellectual property rights (e.g. patents) to innovators prior to (and independently of) investment in innovative projects. However, while allocating monopoly rights to intellectual property could solve the problem of starting to invest too early, it fails to protect the financiers from the pressure to continue investing for too long. Should contract rights be used instead?

Both contract and intellectual property rights specify the relationship between a party and a corpus (the "property"). Property rights are "rights good against the world."[17] In contrast, contract rights are "rights good against the other contracting party."[18] Intellectual property law defines "a relationship of a party to the "property" in terms independent of any relationship between the rights owner and a third party." Contract rights "depend on the existence of a voluntary relationship" among parties to a contract.[19]

The decision to approach an investor with a proposal to finance innovation depends on whether or not anyone in the rest of the world can do the same. As argued by Nelson (1959), Barzel (1968) and many others, if intellectual property rights are not well-defined, i.e. not allocated to a specific innovator, then competition leads to premature financing of innovation. Intellectual property rights establish who has a claim on the property, but neither require nor preclude the existence of any financing agreement.

In contrast, the decision to stop financing an ongoing project depends on the agreement between the parties involved. The rest of the world only plays a role insofar as it offers alternative financing opportunities. Thus, the efficiency of the final outcome depends on the choice and availability of voluntary restraints on the behavior of both the innovator and the financier, e.g. a contract.

Thus, mechanisms that are able to can mitigate the problem of overinvestment in innovation are designed as contractual provisions rather than intellectual property rights.

7.2 Efficiency-enhancing provisions in venture capital contracts

From the point of view of mechanism design, efficiency-enhancing restrictions could be viewed as combinations of entry, continuation, and exit provisions. While all three types of provisions are negotiated prior to the allocation of resources, they differ in their design and purpose and, thus, warrant separate treatment.

7.2.1 Entry

Efficiency-enhancing entry provisions protect investors from future competition. At the beginning of a relationship, the parties must agree on the value of the project, the investment schedule, and the allocation of control rights. Innovators prefer to have the project valued as high as possible; to receive a maximum amount of financing at a minimal loss of share in future returns; and to have full control over all resources. Investors prefer the opposite.

[17] ProCD, Inc. v. Zeidenberg, 86 F.3d 1447, 1454 (7th Cir. 1996).
[18] Nimmer (1998).
[19] Nimmer (1998).

Venture capital contracts protect investors from competition through staged financing, the use of convertible securities, and allocation of extensive control rights to investors. Staged financing allows the investor to abandon a project deemed "bad".[20] The use of convertible securities allows the investor to shift project-specific risk to the innovator and, thus, improve her risk-reward profile.[21] Extensive control rights enables investors to deal with the agency aspects of financing and help ensure that the contract is renegotiation-proof.

7.2.2 Additional financing

Efficiency-enhancing continuation provisions insulate investors from competition between the first injection of financial resources and the exit point. The parties must agree on the number of investors and the procedure of adding or changing investors. Innovators prefer the entry of investors to be free. Investors prefer to restrict the competition.

In venture capital contracts, these provisions are manifested by the preferred stock designation, or a separate investor rights agreement, typically containing special rights enjoyed by preferred stockholders (e.g. original investors), including board representation, observation rights, information rights, preemptive rights, approval rights, rights of first refusal, and protective provisions, such as negative covenants.[22]

A pre-emptive right gives the investor a right (but not an obligation) to participate in subsequent financing rounds to the extent necessary to ensure that her ownership of the project is not diluted in the new financing round. This allows the innovator to retain some financial flexibility, while offering an anti-dilution protection to the investor.

If the terms of a new financing round imply an upward revision in the value of the project, then the original investor can preserve her original share of ownership by injecting additional capital.[23]

If the terms of a new financing round are such that the value of the original claims declines (a so-called "down round"), then the original investor can use an agreed upon method to protect her original investment from a lower valuation. According to a full-ratchet method, the original investor's share in the project is re-calculated at the terms of the new financing round. This method is highly disadvantageous to the innovator. A more fair method is a to re-value the stake of the original investor by computing a weighted average of the new and old terms.[24]

[20] See, for example, Sahlman (1990), Gompers (1995).

[21] See, for example, Sahlman (1991).

[22] See, for example, Cole and Sokol (1997).

[23] For example, suppose that the project is originally valued at 1 million dollars, of which the original investor and innovator each own 50 percent. Suppose also that a new investor is willing to pay additional 500,000 dollars to acquire a 25 percent share of the project's payoff. If the original investor wishes to maintain her original ownership level, she needs inject 500,000 more dollars.

[24] Continuing with the example above, if a new investor buys a 25 percent stake in the new company for 200,000 dollars, under a full ratchet method, the share of the original investor (500,000 dollars) would

The innovator wishes to limit the use of costly anti-dilution adjustments and pre-emptive rights in future financing rounds. A standard way to do this is through "pay to play" provisions which require the investor to commit to financing her share of the next round in order to use pre-emptive rights. Pre-emptive rights may also terminate when an investor's ownership falls below a specified level.

7.2.3 Exit

Efficiency-enhancing exit provisions protect investors from competition at the point of exit. The parties must agree on an exit strategy. A successful exit could be triggered by achieving or exceeding a target return on investment. Exit could also be triggered by an adverse outcome (e.g. inadequate project results) that is not due to poor performance of either party. In addition, exit could be triggered by a failure to meet performance criteria by one party.[25]

In venture capital contracts, the exit strategy is contained in the exit rights agreement or in the registration rights agreement and the stockholders agreement.[26] Although the exit strategy does not set a specific date for the exit, venture capital funds typically have a limited life and favor projects that exit in 5 to 7 years.

There are several lines of defense against competition on exit. Firstly, there are contractual restrictions on the sale or transfer of securities, which prohibit the innovator from selling her share in the project during a specified period of time, typically 3 to 5 years.

After the expiration of a compulsory holding period, defense against competition on exit is specified in the so-called "piggyback rights", which give venture capitalists a right to have their shares included in a sale to the public. Other typical exit rights are "tag along" rights, which give the investors a right to join in any sales of securities by other parties, and "drag along" rights, which enable investors to require that the innovator and other parties sell their shares to a third party.

Another common exit provision in venture capital contracts is a right to cause a sale. This right enables an investor to initiate a sale of the project. This right may or may not be exercised at any time and at any price. Sometimes, venture investors agree to a holding period so that the innovator could implement or change the original business plan. In addition, sometimes the parties agree that the project cannot be sold by less than a pre-specified minimum value.

A very strong defense against competition on exit is imbedded in the right of first refusal, the right of first offer, or the right to negotiation. The right of first refusal allows the investor

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increase to 62.5 percent, leaving the innovator with the remaining 12.5 percent of ownership. Under the weighted average method, the stake of the original investor will decline to about 45 percent. In order to remain undiluted, the original investor will need to inject 54,000 dollars.

[25] On exit strategies, see Cumming and MacIntosh (2001), and Bascha and Walz (2001).

[26] See, for example, Cole and Sokol (1997).

to match the terms of an outside to the innovator prior to the transaction. Combined with the tag along right, this right offers a protection that the investor will get a fair value for her share of the project. Namely, if the innovator is willing to sell to a third party at a low price, the investor could exercise the right of first refusal and benefit from the transaction. Alternatively, if the selling price is high, the investor could tag along. A right of first offer requires the innovator to make an offer to the existing investor prior to pursuing any outside opportunities to sell her shares of the project. If the existing investor refuses to buy them at a given price, the innovator is free to sell them to a third party for the price that is greater or equal to the one offered to the original investor. A right of negotiation only requires the parties to negotiate in good faith prior to a sale of the portion of or the entire project.

8 Conclusion

In this paper I show that in the environment of imperfect information and costly learning, competitive investors overinvest in innovation. From the social welfare perspective, it is optimal to stop investing in any project that has not exited at the point of maximum expected profits. Even if a project turns out to be good, the resources could have earned higher returns elsewhere in the economy. However, competition drives rational investors to continue financing in excess of the social optimum and leads to a waste of resources.

I also show that for a general set of preferences, there does not exist a mechanism that implements a socially optimal investment level as a Nash equilibrium of a noncooperative game. Competitive investors are unable to effectively allocate project-specific risk. They take on too much idiosyncratic risk compared to a social optimum.

However, I argue that the impossibility result may be circumvented for a modified choice rule. Without the loss of generality, I construct a monotonic choice rule that implements outcomes ϵ-close to those selected by the socially optimal rule, where ϵ is a function of the number of investors allowed to finance the project.

I conjecture that contractual provisions that restrain entry of new investors, while ensuring exit of existing investors can mitigate the problem of overinvestment in innovation. Efficiency-enhancing provisions protect investors from competition at the point of entry, continuation, and exit from the project. The conjecture is supported by such typical provisions in venture capital contracts as pre-emptive rights, approval rights, rights of first refusal, demand rights, and exit rights.

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