Appendices

A A Simple Model of Contagion in Venture Capital

Given the structure of venture capital financing just described, the potential mechanisms by which shocks might propagate across companies in a venture firm's portfolio would have to be quite different from those at work in other contexts. Below, I provide a simple model to illustrate that, unlike in most other settings, contagion could go in either direction in venture capital.

A.1 A Single-Fund Venture Firm

I begin by considering a venture firm that raises a single fund at time $t = 0$, which it must fully invest.[1] Four subsequent events happen in the life of the fund: 1) first-round investments are made, 2) the quality of those investments are realized, 3) second-round investments are made, and 4) payoffs are realized. The timeline is illustrated in Panel (a) of Figure A.1. The size of the fund, F, is taken to be exogenous. After the fund is raised, two potential projects (indexed by i) arrive for first-round investments. At time $t = 1$ the venture firm learns the quality of the projects in which it made first-round investments and can then make second-round investments at time $t = 1\,{}^{1}\!/_{2}$. The payoff for a second-round investment is a function of the amount invested and the quality of the project. For an investment of size x_i in project i the payoff is given by $\theta_i f(x_i)$, where θ_i captures project quality. In what follows, I will assume this payoff function takes the form $f(x) = \sqrt{x}$. The discount rate will also be assumed to be zero.

First-round investment decisions are abstracted away from in the model by assuming the cost of these investments is zero. Thus, the venture firm will always choose to make first-round investments in both projects. This is done because I am primarily interested in continuation financing decisions on existing portfolio companies. In the single-fund case, it would be equivalent to think of the model as starting at time $t = 1$, with two existing portfolio companies and F dollars of uninvested capital remaining to invest in them.

At time $t = 1\,{}^{1}\!/_{2}$ the venture firm is assumed to maximize the terminal payoff of its investments,

[1] In reality, it is not typically required that all committed capital be invested, but returning capital to limited partners is rare. This is most likely due to management fees that would be lost as well as the negative signal it would send about the venture firm's deal flow.

subject to the constraint that it must put all its capital to work. Thus, it solves the problem:

$$\max_{x_i, x_j} \quad \theta_i \sqrt{x_i} + \theta_j \sqrt{x_j} \tag{A.1}$$

$$s.t. \quad x_i + x_j = F. \tag{A.2}$$

It is then straightforward to show that optimal investment is given by $x_i = F\frac{\theta_i^2}{\theta_i^2+\theta_j^2}$, leading to a payoff of $v = \sqrt{F(\theta_i^2 + \theta_j^2)}$, where j indexes the project that is not i. In addition, it is easy to see that investment in i increases as the quality of project j decreases:

$$\frac{\partial x_i}{\partial \theta_j} = \frac{-2F\theta_i^2\theta_j}{(\theta_i^2 + \theta_j^2)^2} < 0. \tag{A.3}$$

This is what was referred to earlier as reverse contagion. It occurs because the venture firm has a fixed amount of capital that it must invest. Thus, project i receives more capital when the prospects of project j decline, even if the prospects for project i remain unchanged. Here, the venture firm engages in *relative* evaluation.[2] One could think of project i as representing the non-IT portion of a generalist venture firm's portfolio, and project j as representing the internet portion. The collapse of the technology bubble would be represented in this simple model by a low realization of θ_j, leading to high investment in non-IT companies.

A.2 A Two-Fund Venture Firm

Now, I extend the model by assuming that at time $t = 1\,1/4$, after learning the quality of its existing portfolio companies, but before making second-round investments, the venture firm will raise a second fund (Fund II) of size F_{II}. The timing of events for the second fund is just like the first. Again, immediately after fundraising, first-round investments can be made in two new projects at zero cost. Then at time $t = 2$ the quality of these projects will be realized and second-round investments will be made, with payoffs occurring the following period. Panel (b) of Figure A.1 illustrates the timing for both funds.

The only difference in Fund II is that uninvested capital left over from Fund I, $F_I - x_{i1} - x_{j1}$, can

[2] This relates closely to the "bright side" view of internal capital markets. For theoretical work in this area, see Williamson (1975); Meyer, Milgrom, and Roberts (1992); Gertner, Scharfstein, and Stein (1994); Stein (1997); Scharfstein and Stein (2000); Rajan, Servaes, and Zingales (2000). For particularly related empirical work, see Lang, Ofek, and Stulz (1996); Lamont (1997); Shin and Stulz (1998); Rajan, Servaes, and Zingales (2000); Ozbas and Scharfstein (2010). Indeed, although diversified conglomerates are not generally considered financial intermediaries, venture capital firms do resemble them in some ways. However, there are limits to this analogy. First, venture firms cannot invest cash flows from one portfolio company into another. Second, venture-backed companies are generally free to raise follow-on rounds from any venture firm, whereas divisions of a conglomerate are legally bound to it.

also be invested in its portfolio companies in the second round. However, capital from Fund II cannot be used to invest in Fund I portfolio companies. This is meant to reflect the cross-fund investing restrictions mentioned earlier. Now at time $t = 2\,1/2$ the venture firm solves the same constrained optimization problem as in the single-fund case, with uninvested capital of $F_{II} + F_I - x_{i1} - x_{j1}$. This means that the expected payoff from the fund's portfolio companies, as of time $t = 1\,1/2$, is given by $\mathbb{E}[v_2] = k\sqrt{(F_{II} + F_I - x_{i1} - x_{j1})}$, where $k \equiv \mathbb{E}[\sqrt{(\theta_{i2}^2 + \theta_{j2}^2)}]$. Understanding this, the venture firm now solves the following problem at time $t = 1\,1/2$:

$$\max_{x_i, x_j} \quad \theta_{i1}\sqrt{x_{i1}} + \theta_{j1}\sqrt{x_{j1}} + k\sqrt{(F_{II} + F_I - x_{i1} - x_{j1})} \tag{A.4}$$

$$s.t. \quad x_{i1} + x_{j1} \leq F_I. \tag{A.5}$$

In this case, when the inequality constraint is non-binding, optimal investment is given by:

$$x_{i1} = \frac{(F_{II} + F_I)\theta_{i1}^2}{k^2 + \theta_{i1}^2 + \theta_{j1}^2} \tag{A.6}$$

$$\Rightarrow \frac{\partial x_{i1}}{\partial \theta_{j1}} = \frac{-2(F_{II} + F_I)\theta_{i1}^2\theta_{j1}}{(k^2 + \theta_{i1}^2 + \theta_{j1}^2)^2} < 0. \tag{A.7}$$

When the inequality constraint is binding, optimal investment is the same as in the one-fund case.

Proposition 1. *In the two-fund case without performance-sensitive fundraising, reverse contagion ($\frac{\partial x_{i1}}{\partial \theta_{j1}} < 0$) still occurs in the region of the parameter space in which the inequality constraint is non-binding; however, it is mitigated (the magnitude of $\frac{\partial x_{i1}}{\partial \theta_{j1}}$ is lower than in the one-fund case).*

Proof. See Appendix B. □

The intuition behind this proposition is straightforward, as the capital that is not invested in project j can now be saved for next period rather than needing to be invested immediately in project i. Thus, future fundraising/investing can dampen the degree of reverse contagion.

A.3 A Two-Fund Venture Firm with Performance-Sensitive Fundraising

Now, I allow F_{II} to be a function of the average quality of projects realized in period 1: $F_{II} = b(\frac{\theta_{i1}+\theta_{j1}}{2})$. This is a reduced form way of capturing the idea that limited partners will be more reluctant to invest in a follow-on fund if the previous fund appears to have poor interim performance (Kaplan and Schoar, 2005). This could be incorporated into a richer model by allowing limited partners to learn about the talent of general partners through interim performance. The parameter, b, above, captures the flow-to-performance sensitivity of a venture firm. In this case, when the inequality constraint is non-binding, optimal investment at time 1 will be given by:

$$x_{i1} = \frac{(b(\frac{\theta_{i1}+\theta_{j1}}{2}) + F_I)\theta_{i1}^2}{k^2 + \theta_{i1}^2 + \theta_{j1}^2} \tag{A.8}$$

$$\Rightarrow \frac{\partial x_{i1}}{\partial \theta_{j1}} = \frac{\theta_i^2(b(k^2 + \theta_i^2 - 2\theta_i\theta_j - \theta_j^2) - 4F_I\theta_j)}{2(k^2 + \theta_{i1}^2 + \theta_{j1}^2)^2}. \tag{A.9}$$

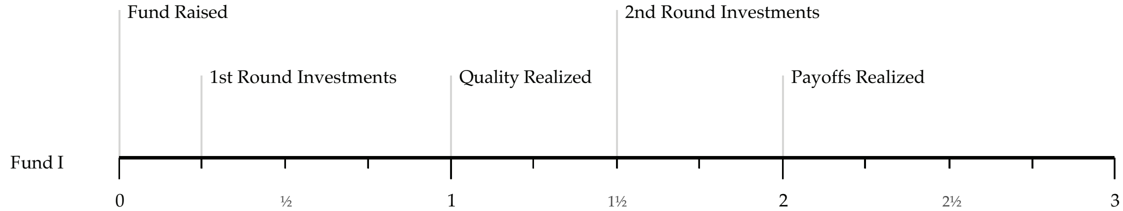
Proposition 2. *In the two-fund case with performance-sensitive fundraising, there exists b^* such that for $b > b^*$ ordinary contagion occurs ($\frac{\partial x_{i1}}{\partial \theta_{j1}} > 0$) in the region of the parameter space in which the inequality constraint is non-binding.*

Proof. See Appendix B. □

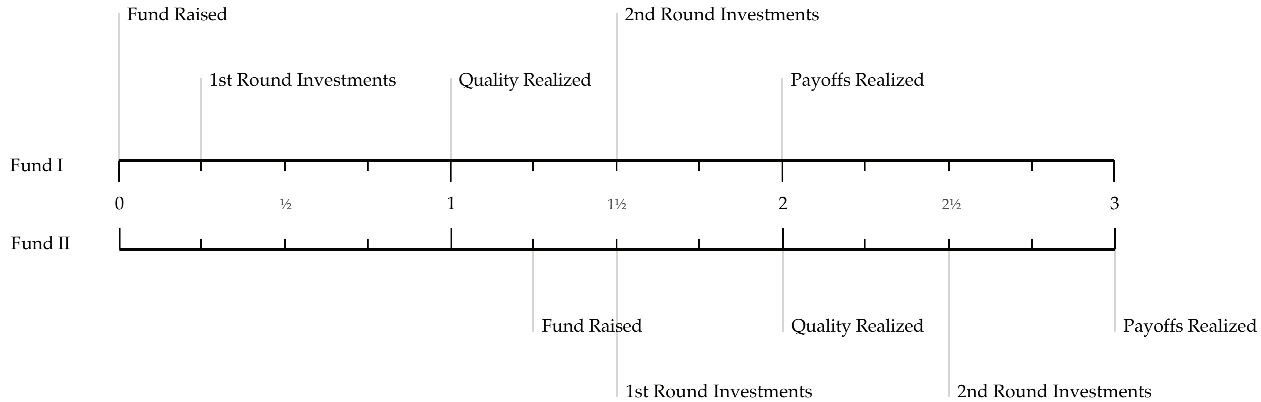
Thus, for a venture firm whose fundraising is sufficiently sensitive to performance, investment in project i can now decline with the realized quality of project j. The reason is that the decreased quality of project j leads to a smaller second fund. This decline in total resources creates a force for decreased investment in both existing projects, which can outweigh the increased relative attractiveness of project i with respect to project j. This is true even despite the assumed cross-fund investing restrictions. Moreover, while the cross-fund investing restrictions in the model allow Fund I to invest in the second-round of Fund II projects, even this is not critical. For example, one could think of the second-round investments at time $t = 2\,1/2$ as first-round investments and all of the results would remain unchanged. Intuitively, what is important is that some of the capital that would have gone into new projects from the new fund will now come from the old fund. Indeed, as long as funds overlap temporally, there will always be semi-fungibility across funds, regardless of restrictions.

Figure A.1
Timeline

(a) **Single-Fund Venture Firm**



(b) **Two-Fund Venture Firm**



B Proofs

Proposition 1. *In the two-fund case without performance-sensitive fundraising, reverse contagion* ($\frac{\partial x_{i1}}{\partial \theta_{j1}} < 0$) *still occurs in the region of the parameter space in which the inequality constraint is non-binding; however, it is mitigated (the magnitude of* $\frac{\partial x_{i1}}{\partial \theta_{j1}}$ *is lower than in the one-fund case).*

Proof. The first part of the proposition is trivial given Equation A.6. To see the second part, note that the inequality constraint is non-binding if and only if:

$$\begin{aligned} x_{i1} + x_{j1} &\leq F_I && \text{(B.1)} \\ \Leftrightarrow \frac{(F_I + F_{II})\theta_{i1}^2}{k^2 + \theta_{i1}^2 + \theta_{j1}^2} + \frac{(F_I + F_{II})\theta_{j1}^2}{k^2 + \theta_{i1}^2 + \theta_{j1}^2} &\leq F_I && \text{(B.2)} \\ \Leftrightarrow F_{II} &\leq \frac{F_I k^2}{\theta_{i1}^2 + \theta_{j1}^2}. && \text{(B.3)} \end{aligned}$$

In this region of the parameter space, investment in project i is less sensitive to the quality of project j in the two-fund case than in the one-fund case if and only if:

$$\begin{aligned} \frac{2(F_{II} + F_I)\theta_{i1}^2\theta_{j1}}{(k^2 + \theta_{i1}^2 + \theta_{j1}^2)^2} &< \frac{2F_I\theta_{i_1}^2\theta_{j_1}}{(\theta_{i1}^2 + \theta_{j1}^2)^2} && \text{(B.4)} \\ \Leftrightarrow \sqrt{\frac{F_I + F_{II}}{F_I}} &< \frac{k^2 + \theta_i^2 + \theta_j^2}{\theta_i^2 + \theta_j^2}. && \text{(B.5)} \end{aligned}$$

Given B.3, the expression on the left-hand side of B.5 is bounded above. Thus, it is sufficient to show that:

$$\begin{aligned} \sqrt{\frac{F_I + \frac{F_I k^2}{\theta_{i1}^2 + \theta_{j1}^2}}{F_I}} &< \frac{k^2 + \theta_i^2 + \theta_j^2}{\theta_i^2 + \theta_j^2} && \text{(B.6)} \\ \Leftrightarrow \sqrt{\frac{k^2 + \theta_i^2 + \theta_j^2}{\theta_i^2 + \theta_j^2}} &< \frac{k^2 + \theta_i^2 + \theta_j^2}{\theta_i^2 + \theta_j^2} && \text{(B.7)} \\ \Leftrightarrow 0 &< k^2 && \text{(B.8)} \end{aligned}$$

□

Proposition 2. *In the two-fund case with performance-sensitive fundraising, there exists* b^* *such that for* $b > b^*$ *ordinary contagion is present* ($\frac{\partial x_{i1}}{\partial \theta_{j1}} > 0$) *in the region of the parameter space in which the inequality constraint is non-binding.*

Proof. Now the inequality constraint is non-binding if and only if:

$$F_{II} \leq \frac{F_I k^2}{\theta_{i1}^2 + \theta_{j1}^2} \tag{B.9}$$

$$\Leftrightarrow b\frac{(\theta_{i1} + \theta_{j1})}{2} \leq \frac{F_I k^2}{\theta_{i1}^2 + \theta_{j1}^2} \tag{B.10}$$

$$\Leftrightarrow (\theta_{i1} + \theta_{j1})(\theta_{i1}^2 + \theta_{j1}^2) \leq \frac{2F_I k^2}{b} \tag{B.11}$$

$$\Rightarrow \theta_{i1} \leq (\frac{2F_I k^2}{b})^{\frac{1}{3}},\ \theta_{j1} \leq (\frac{2F_I k^2}{b})^{\frac{1}{3}}. \tag{B.12}$$

Ordinary contagion requires:

$$\frac{\partial x_{i1}}{\partial \theta_{j1}} > 0 \tag{B.13}$$

$$\Leftrightarrow \frac{\theta_{i1}^2[b(k^2 + \theta_{i1}^2 - 2\theta_{i1}\theta_{j1} - \theta_{j1}^2) - 4F_I\theta_{j1}]}{2(k^2 + \theta_{i1}^2 + \theta_{j1}^2)^2} > 0 \tag{B.14}$$

$$\Leftrightarrow b(k^2 + \theta_{i1}^2 - 2\theta_{i1}\theta_{j1} - \theta_{j1}^2) - 4F_I\theta_{j1} > 0. \tag{B.15}$$

Because θ_{i1} and θ_{j1} are bounded above as in B.12, the left-hand side of B.15 is bounded below by:

$$b(k^2 - 2(\frac{2F_I k^2}{b})^{\frac{2}{3}}) - 4F_I(\frac{2F_I k^2}{b})^{\frac{1}{3}}. \tag{B.16}$$

The limit of this expression as b goes to infinity is infinity. Therefore, by definition, there exists a b^* such that for all $b > b^*$, this expression is positive. □

C Additional Results

Table C.1
Alternative Definition of Internet Exposure

This table replicates Table 4 but defines *InternetExposure* based on the five years leading up to the peak of the bubble rather than ten years. Raw coefficients are reported. * and ** denote statistical significance at the 10% and 5% level, respectively.

	Whole Syndicate			Lead VC		
	(1)	(2)	(3)	(4)	(5)	(6)
Post	0.0728	0.0604	0.105	0.0996	0.0721	0.183
	[0.0624]	[0.0648]	[0.119]	[0.0635]	[0.0644]	[0.136]
Internet Exposure	0.489^{**}	0.508^{**}	0.486^{**}	0.337	0.295	0.303
	[0.177]	[0.183]	[0.182]	[0.233]	[0.217]	[0.216]
Post × Internet Exposure	-0.899^{**}	-0.764^{**}	-0.706^{**}	-0.783^{**}	-0.619^{**}	-0.633^{**}
	[0.232]	[0.242]	[0.244]	[0.249]	[0.252]	[0.255]
Region FE	No	Yes	Yes	No	Yes	Yes
Sector FE	No	Yes	Yes	No	Yes	Yes
Stage FE	No	Yes	Yes	No	Yes	Yes
Post × Region FE	No	No	Yes	No	No	Yes
Post × Sector FE	No	No	Yes	No	No	Yes
Post × Stage FE	No	No	Yes	No	No	Yes
Spells	5,838	5,822	5,822	5,243	5,213	5,213

Table C.2
Alternative Definition of Non-IT

This table replicates Table 4 using different samples. In Column (1), consumer-related non-IT companies are excluded from the sample. In Column (2), non-IT companies categorized as producing "Other Products" are excluded from the sample. In Column (3), non-IT companies with the words "Internet," "Online," "Web," "E-Commerce," "Software," "Digital," "Electronic," "Computer," "E-mail," "Hardware," or "Network" in the detailed business description, product keywords, or technology description are excluded. In Column (4), companies that are categorized by VentureSource as IT are excluded. Raw coefficients are reported. Standard errors are in brackets and are clustered by portfolio company in the first three columns as well as lead venture firm in the final three columns, as in Cameron, Gelbach, and Miller (2011). * and ** denote statistical significance at the 10% and 5% level, respectively.

	Lead VC			
	(1) Ex. Consumer-Related	(2) Ex. Other Non-IT	(3) Ex. Tech Description	(4) Ex. VentureSource IT
Post	0.129	0.194	0.158	0.202
	[0.142]	[0.134]	[0.137]	[0.135]
Internet Exposure	0.208	0.206	0.247	0.358
	[0.255]	[0.264]	[0.258]	[0.245]
Post × Internet Exposure	-0.604^{**}	-0.730^{**}	-0.629^{**}	-0.757^{**}
	[0.303]	[0.303]	[0.302]	[0.283]
Region FE	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes
Stage FE	Yes	Yes	Yes	Yes
Post × Region FE	Yes	Yes	Yes	Yes
Post × Sector FE	Yes	Yes	Yes	Yes
Post × Stage FE	Yes	Yes	Yes	Yes
Spells	4,413	4,187	4,665	5,198

Table C.3
The Effect of Internet VC Flows

This table shows the results of estimating Cox proportional hazard models of the form

$$h_{ijt}(\tau) = h_0(\tau)exp(\beta_1 \log(InternetFlows_t) + \beta_2 InternetExposure_{ij} + \beta_3 \log(InternetFlows_t) \times InternetExposure_{ij} + \beta_4 \log(InternetFlows_t) \times InternetExposure_{ij} \times Post_t + \boldsymbol{x}_{ijt}\boldsymbol{\beta}).$$

Analysis time, τ, is defined as the time since company i raised its jth round. The variable $\log(InternetFlows_t)$ represents the log of quarterly aggregate flows into (U.S. based, independent, private) internet-specific venture funds, from Thomson. All other variables are defined as in Table 4. When company controls are included, the most prevalent categories (Northern California, expansion, and medical/health) are omitted. The sample is restricted to financing rounds of venture-backed non-IT portfolio companies based in the U.S. The sample period is from March 31, 1997, to March 31, 2003. Raw coefficients are reported. Standard errors are in brackets and are clustered by portfolio company and quarter in the first three columns as well as lead venture firm in the final three columns, as in Cameron, Gelbach, and Miller (2011). * and ** denote statistical significance at the 10% and 5% level, respectively.

	Whole Syndicate			Lead VC		
	(1)	(2)	(3)	(4)	(5)	(6)
log(Internet Flows)	0.0199	0.0186	0.00885	0.0156	0.0158	−0.00936
	[0.0173]	[0.0185]	[0.0270]	[0.0225]	[0.0232]	[0.0270]
Internet Exposure	0.0266	0.148	0.137	−0.0500	0.0253	0.0317
	[0.170]	[0.165]	[0.163]	[0.204]	[0.184]	[0.184]
log(Internet Flows) × Internet Exposure	−0.0555	−0.0581	−0.0793	−0.0693	−0.0791	−0.0880
	[0.0930]	[0.0896]	[0.0856]	[0.105]	[0.105]	[0.100]
log(Internet Flows) × Internet Exposure × Post	0.287**	0.299**	0.297**	0.340**	0.352**	0.354**
	[0.106]	[0.101]	[0.0984]	[0.109]	[0.104]	[0.102]
Region FE	No	Yes	Yes	No	Yes	Yes
Sector FE	No	Yes	Yes	No	Yes	Yes
Stage FE	No	Yes	Yes	No	Yes	Yes
log(Internet Flows) × Region FE	No	No	Yes	No	No	Yes
log(Internet Flows) × Sector FE	No	No	Yes	No	No	Yes
log(Internet Flows) × Stage FE	No	No	Yes	No	No	Yes
Spells	5,908	5,889	5,889	5,330	5,296	5,296

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