

Specialization, Information Production and Venture Capital Staged Investment

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Specialization, Information Production and Venture Capital Stage Monitoring

ABSTRACT

We present a theoretical model to explain the specialization of venture capitalists in information production as a source of efficiency in venture capital staged investment. In the model, specialized expertise is present when two syndicated venture capitalists assigned to evaluate two components of a project separately or sequentially have a higher probability of observing the true value of the project compared with the case in which two venture capitalists evaluate the two stages jointly and simultaneously. We delineate the circumstances under which sequentially separate evaluation by venture capitalists can yield higher expected payoffs compared with joint evaluation due to efficient specialization and learning in information production. Our model provides theoretical explanation for VCs to focus on different stages or sectors to build up their comparative advantage of expertise.

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1. Introduction

In many economic organizations, specialization and division of labor are not limited to the production of goods and services. They apply also to organization decision-making concerning strategic investments, e.g., venture capital (VC) financing. A common practice in VC financing is staged investment through which VCs select of a start-up project evaluate different aspects of a project that are critical to a project's success. Stage investment arises when several VCs separately and sequentially invest in one startup project. Sahlman (1990) declares that venture capitalists "will invest in early-stage deals, whereas others concentrate on later-stage financings." Barry (1994) states that "venture capitalists typically specialize by emphasizing a particular industry, such as biotechnology, or by emphasizing a particular stage of company development, such as startup companies or companies in the expansion stage."

Venture capitalists are becoming increasingly specializing in VC investment and focusing on different stages of financing or on different industry sectors. For example, some focus on only seed capital while others focus on early stage or growth stage. In staged investment, VCs of the next stages have the advantage of making their decisions based on earlier stage's VC counterparties' assessment, with/without communicating them¹.

Sahlman (1990) and Bygrave and Timmons (1992) suggest that VC partners with the most experience in the particular sector often lead the due diligence while the rest of the syndicated partners make decisions contingent upon receiving positive signals from initial leading VC. Lerner (1994) argues that one potential benefit of VC

¹ The limited communication rule may serve to reduce the possibility of certain individuals exerting their influence over the committee, or to prevent informational free-ridership, when some committee members simply echo the opinion of other members.

syndication is superior selection of investment in the spirit of Sah and Stiglitz (1988), since syndication helps to resolve information uncertainty. Gompers (1995) empirically suggests that staged financing helps resolve information uncertainty particularly in research intensive companies. There are, however, no theoretical studies on whether resolving information uncertainty and improving decision making drive the staged investment for VCs.

The question we are interested in is the following: if information is imperfect in the sense that the venture capitalists cannot always observe or accurately assess the quality of an investment project or specific project components – so that both Type-I error (of rejecting a good project) and Type-II error (of accepting a bad project) may be committed – what is the scope for specialization in due diligence to improve information production? Specifically, what are the circumstances under which stages venture capitalists with specialization in domain expertise evaluate project separately and sequentially will yield higher expected project payoffs compared with those where venture capitalists evaluate a project jointly and simultaneously?

There is also a learning effect. Typically in Silicon Valley's venture capital firms, a general partner (GP) may focus on just one industry or one stage of an industry (e.g. internet web technology or internet search technology). Consequently, such GP will gain certain advantage in assessing start-up companies by specialization in information production. When venture capitalists possess different domain expertise in different stages, specialization may be the only way to optimize the investment evaluation process. With different domain expertise, stages venture capitalists will enjoy not only relative but absolute comparative advantage in producing information.

We present a model to examine the efficiency associated with specialization in due diligence. Our objective is to provide some understanding on venture capital staged investment for better information production. Our theory can therefore explain the value creation associated with VC endeavor of specializing in certain industry, geography or development stages as well as the popularity of VC syndicated investment. Gompers (1995) proposes that VC staged financing is a mechanism to mitigate holdup problem between VCs and entrepreneurs in startups. His theory however, can not explain why different VCs invest in different stages rather. Compliment to Gompers's theory, we offer a theoretical possibility that staged investment also mitigates decision errors when decision-makers are fallible.

Section 2 outlines the model. For simplicity, we only consider two venture capitalists in the model. Section 3 extends the model with learning effect. We conclude our study in Section 4 with a discussion on future research directions.

2. Division of Due Diligence and the Scope for Specialization in Decision-Making

Staged VCs include two GPs that are tasked to evaluate a investment project. The GPs share a common organizational objective to maximize the expected project payoff. Every project has two components or two stages (for simplification) which jointly determine its likelihood of success and the value of its payoff. Specifically, we may think of the two components: first stage is technology feasibility and second stage is market feasibility. Each component is characterized by a signal θ_i , $i = 1, 2$, which, for simplicity, is drawn from an identical uniform distribution, over the support $[-1,1]$. To keep the algebra tractable, we further assume that θ_1 and θ_2 are uncorrelated. The payoff of each project, denoted V , is given by the following:

$$V = \begin{cases} X & \text{if } \theta_1 + \theta_2 > 0 \\ -L & \text{if } \theta_1 + \theta_2 \leq 0 \end{cases} \quad (1)$$

The unconditional expected project payoff in this case is simply

$$EV(\text{no screening}) \equiv EV^0 = \frac{1}{2}[1-k]X \quad (2)$$

where $k \equiv \frac{L}{X}$ is a measure of the quality of the project. In the absence of any information, projects should always be accepted if $k < 1$, and always rejected if $k \geq 1$.

To set the stage for our model, we first consider the case where the investment committee evaluates each project jointly. The committee members exert effort and are able to observe accurately, with probability q , a signal π , which is the aggregate of θ_1 and θ_2 . With probability $(1-q)$, the committee does not observe π . We may consider q as a measure of the committee's expertise in joint project evaluation.

We shall further assume that a single decision-maker does not possess 'generalist' expertise to evaluate the quality of the overall project, so that the probability of observing π by a single decision-maker is zero. Hence, joint project evaluation is the benchmark against which other decision structures involving specialization or partial evaluation are measured against. The investment decision rule for the two-member VCs is as follows:

If π is observed with probability q , accept a project if $\pi > 0$ and reject otherwise; If π is not observed with probability $1 - q$, accept if $k < 1$, and reject otherwise. We suppose that the evaluation effort expended by each decision-maker incurs a monetary cost of c . It is straightforward to show that the expected project payoff is then given by

$$EV(\text{team, no specialization}) \equiv EV^T = \frac{X}{2}q + \frac{X}{2}[1-q]\text{Max}\{0, 1-k\} - 2c \quad (3)$$

The organization can obtain a higher expected payoff by requiring the project to undergo joint evaluation by the two-member committee if $EV^T > EV^0$, i.e.

$$\frac{X}{2}q + \frac{X}{2}(1-q)\text{Max}\{0,1-k\} - 2c > \frac{X}{2}\text{Max}\{0,1-k\} \quad (4)$$

The inequality in (4) simplifies to the following condition regarding the evaluation cost c if joint project evaluation yields higher expected payoff compared with no evaluation:

$$c < \bar{c} \equiv \frac{1}{4}q\text{Min}\{1,k\}X. \quad (5)$$

2.1 Project Evaluation with Specialization

Suppose that general partners possess specialized expertise in evaluating project components. For simplicity, suppose both GPs are identically skilled and has the same probability, denoted p , of observing the true value of a project component. We shall consider two cases of division of labor in information production by focusing on different stages. In the first case, only a single GP is assigned to conduct a partial evaluation of the project; i.e. he is asked to evaluate only one component of the project. In the second case, both GPs are assigned to evaluate separate components of the project.

In general, given that the two project components are identically distributed, the assignment of decision-makers to evaluate a particular project component would depend on the relative expertise of the two decision makers. When GP j ($= 1, 2$) evaluates project component i ($= 1, 2$), he or she observes signal θ_i accurately with probability p_i^j . GP 1 is said to have a *comparative advantage* in evaluating project component i , while GP 2 has a comparative advantage in evaluating project component j , if the condition $\frac{p_i^1}{p_j^1} > \frac{p_i^2}{p_j^2}$ holds. Therefore, when both GPs are assigned to evaluate separate project components, GP 1 should be assigned to evaluate component i while GP 2 should be assigned to evaluate component j . In the case of partial project

evaluation, where only one project component is to be evaluated, the GP with the higher probability of observing the true value of the project component should be assigned to the task. In this case, it is possible that a GP, say j , may possess an *absolute advantage* over decision-maker m in observing both project components, i.e. $p_1^j > p_1^m$ and $p_2^j > p_2^m$. We shall take up this issue again in Section 3.

2.2 Partial Project Evaluation with One General Partner

Consider the case where one GP is assigned to conduct an evaluation of only one project component, say component 1, and then makes an investment decision based on the partial evaluation. Even in this restricted case, expected *gross* project payoff can be higher than in the case where decision makers evaluate projects jointly, if the GP is sufficiently skilful in his expertise in one project component.

A necessary condition for division of labor and specialization in information production to be desirable is that p must be greater than q . This condition simply requires that when the single GP evaluates one project component, the probability that the value of the project component is observed exceeds the probability that the value of the overall project is observed by the committee in a joint evaluation. The higher probability of p may reflect the existence of specialized skills or the effects of learning-by-doing on the job that allow the expertise of the GP to be sharpened. We assume that effort cost of evaluation for each GP is c , the same as in the case where he participates in the joint evaluation of the project.

Without the benefit of potentially observing θ_2 , the single GP assigned to evaluate only component 1 must first decide on a threshold $\bar{\theta}_1$, such that conditional on observing signal θ_1 , the project will be recommended for acceptance only if $\theta_1 > \bar{\theta}_1$. The expected project payoff when $\theta_1 = \bar{\theta}_1$ is given by

$$EV(\text{one manager screens one component, } \theta_1 = \bar{\theta}_1 \mid \text{observes signal}) \quad (6)$$

$$\begin{aligned}
&= \text{Prob}(\bar{\theta}_1 + \theta_2 > 0)X - \text{Prob}(\bar{\theta}_1 + \theta_2 \leq 0)kX \\
&= \frac{X}{2}[1 + \bar{\theta}_1] - \frac{X}{2}[1 - \bar{\theta}_1]k
\end{aligned}$$

Setting the conditional expected payoff to zero yields the optimal cutoff point

$$\bar{\theta}_1 = \frac{k-1}{k+1} \quad (7)$$

In the event that the GP is unable to observe an informative signal for component 1, the decision rule is to accept the project if $k < 1$ and reject the project if $k \geq 1$, as in the case where no evaluation is conducted. Denote EV^{S1} as the unconditional expected payoff when one GP is assigned to evaluate a project component. We have

$$\begin{aligned}
EV^{S1} &= p \left\{ \frac{X}{2} \int_{\frac{k-1}{k+1}}^1 \left[\frac{1+\theta_1}{2} - \frac{1-\theta_1}{2}k \right] d\theta_1 \right\} + (1-p) \text{Max} \left\{ 0, \frac{1}{2}[1-k]X \right\} - c \\
&= \frac{X}{2} \left\{ \frac{p}{k+1} + (1-p) \text{Max} \{0, 1-k\} \right\} - c
\end{aligned} \quad (8)$$

Comparing the expected project payoffs under joint evaluation by the committee against the case when one manager is assigned to evaluate a single project component,

$$EV^{S1} - EV^T = \frac{X}{2} \left\{ \frac{p}{k+1} + (1-p) \text{Max} \{0, 1-k\} - q - (1-q) \text{Max} \{0, 1-k\} \right\} + c \quad (9)$$

This comparison simplifies to

$$EV^{S1} > (<) EV^T \text{ if } p > (<) p^{S1}(q, k) \equiv \frac{(k+1)}{\text{Min}[1, k]}q - \frac{2(k+1)}{\text{Min}[1, k^2]}c \quad (10)$$

The result in (10) indicates that assigning a single GP to conduct a partial evaluation of the project can improve expected project payoff, compared with joint evaluation by the committee, only if the probability of observing an informative signal p for a project component, is greater than the threshold set by $p^{S1}(q, k)$.

Let $\phi^{S1}(q,k) \equiv 1 - p^{S1}(q,k)$ denote the scope for partial evaluation by one manager to yield higher expected payoffs. Since $\phi^{S1}(q,k)$ decreases with q , this implies that the scope for partial evaluation to improve organizational performance is smaller if the two-member committee is very skilful at joint evaluation (i.e. q is higher). In fact, if q is greater than $\frac{\text{Min}[1,k]}{k+1} + \frac{2}{\text{Min}[1,k]X}c$, so that $p^{S1}(q,k) > 1$, partial evaluation will never dominate joint evaluation (and $\phi^{S1}(q,k)$ will be negative in this case). For a given q , partial evaluation becomes more attractive if the evaluation cost c is higher, as one might expect. The tradeoff here is the reduction in evaluation cost against the loss of information from the partial evaluation. It is straightforward to prove the first result.

Proposition 1: The scope for optimal partial evaluation by one GP, $\phi(q,k)$, is decreasing (increasing) in the quality of the projects, k , for $k < (>) 1$. As k tends to zero or infinity, $p^{S1}(q,k)$ tends to 1, so that partial project evaluation is never beneficial when the quality of the projects is either very good or very bad. The scope for partial evaluation to yield a higher expected payoff, compared with joint evaluation, is greatest when the project quality is neutral, i.e. when $k = 1$.

The intuition behind Proposition 1 is that the economic impact of making the wrong investment decisions with partial evaluation is greater when $k \neq 1$ (Type-I error of rejecting a good project when $k < 1$ and Type-II error of accepting a bad project when $k > 1$), so that partial project evaluation (of one component) is less desirable in this case. This follows from our assumption that the two signals, θ_1 and θ_2 are uncorrelated. In Figure 1, we plot $p^{S1}(q,k)$ against q , for various cases of k , with $c = 0$.

INSERT FIGURE 1

To summarize the analysis thus far, what we have shown is that while partial project evaluation with one manager does not always improve organizational performance, there exists a range of circumstances under which partial evaluation can dominate joint project evaluation. From Figure 1, it is also clear that if $p < q$, i.e. when specialized expertise is absent, partial evaluation will not improve organizational performance.

2.4 Specialization in Project Evaluation with Two General Partners

We turn now to consider the case where both GPs are assigned to evaluate separate components of each investment project. Since GPs are identical in their expertise and possess the same probability p of observing an informative signal for component 1 or 2, they can be assigned to evaluate either one of the components. GPs are able to communicate their information perfectly in the event that each one observes an informative signal for the component that he or she is assigned to evaluate.

The investment decision rule is as follows.

- (i) First, if neither GP observes an informative signal, the decision rule is to accept the project if $k > 1$, and reject if $k \leq 1$. This situation occurs with probability $(1-p)^2$, with an expected payoff of $\text{Max}\left\{0, [1-k]\frac{X}{2}\right\}$.
- (ii) Next, in the case when only one GP observes an informative signal (occurring with probability $2p(1-p)$), the manager who observes the informative signal would set a cutoff point of $\bar{\theta}_i$ such that the project would be recommended for investment if the signal exceeds $\bar{\theta}_i$. It is easy to see that the optimal cutoff

point in this case is set at $\frac{k-1}{k+1}$, the same level as in Section 3.1 for the case when only one GP is assigned to conduct partial evaluation. The expected project payoff is $\frac{X}{2(k+1)}$.

- (iii) Finally, if both GPs observe informative signals, they aggregate the signals, and the project is accepted if and only if $\theta_1 + \theta_2 > 0$; otherwise the project is rejected. This case occurs with probability p^2 , with an expected payoff of $\frac{X}{2}$.

A natural question to ask is: how does the final case (iii) we just described differs from the situation when both GPs evaluate the project jointly and observe an overall signal π , with a probability of q ? More specifically, how does p^2 relate to q ? One may think of several possible effects that can exert an influence on the relationship between p and q . Firstly, if the expertise of GPs is complementary, this may give a rise to “positive externalities” in the evaluation process, so that $q > p^2$. For instance, if one GP is a financial expert and another is a technology expert, but both possess a good understanding or exposure to the other area, then joint evaluation may lead to a higher probability of observing the true value of the overall project, compared with specialization and division of labor.

On the other hand, if both GPs are competent only in their own field, but has very little understanding of the other aspects of the project, joint evaluation in this case may reduce the capacity of the GPs to observe the true value of the overall project since the attention of each GP is spread over the different project components. It might be better for each manager to concentrate on a specific task. Furthermore, most real-world committees are susceptible to free-ride and influence, so that group decision-making may sometimes turn out to be less informative than if GPs were

assigned specific tasks to work on independently. In this case, it is possible that $p^2 \geq q$, so that division of labor, by allowing more focused attention, could lead to a higher probability of observing the overall value of the project. We shall consider both cases below.

Denote EV^{S^2} as the unconditional expected project payoff when GPs are assigned to evaluate separate components of a project.

$$EV^{S^2} = p^2 \frac{X}{2} + 2p(1-p) \frac{X}{2(k+1)} + (1-p)^2 \text{Max} \left\{ 0, \frac{1}{2}[1-k]X \right\} - 2c \quad (11)$$

Comparing the expected project payoffs under specialization in project evaluation with the case of joint evaluation by the committee,

$$EV^{S^2} > (<) EV^T \text{ if } p^2 + \frac{2p(1-p)}{(k+1)} + (p^2 - 2p + q) \text{Max} \{0, [1-k]\} - q > (<) 0 \quad (12)$$

The condition under which specialization in project evaluation yields a higher (lower) expected payoff compared with joint evaluation can be shown to be:

$$EV^{S^2} > (<) EV^T \text{ if } p > (<) p^{S^2}(q, k) \equiv \begin{cases} \frac{-k + \sqrt{k^2 + (1-k^2)q}}{1-k} & \text{if } k < 1 \\ q & \text{if } k = 1 \\ \frac{-1 + \sqrt{1 + (k^2 - 1)q}}{k-1} & \text{if } k > 1 \end{cases} \quad (13)$$

Let $\phi^{S^2}(q, k) \equiv 1 - p^{S^2}(q, k)$ denote the scope for specialized project evaluation by a two-member committee to yield higher expected payoffs. It is easy to verify that $p^{S^2}(q, k)$ is increasing in q , and that $p^{S^2}(0, k) = 0$ and $p^{S^2}(1, k) = 1$. Moreover, $p^{S^2}(q, k)$ is decreasing (increasing) in k for $k < (>) 1$. It follows that $p^{S^2}(q, k) > q$ for $k \neq 1$.

Utilizing (13), it follows that $\phi^{S^2}(q, k)$ is decreasing in q , and increasing (decreasing) in k when k is less (greater) than 1. Therefore, the scope for division of

labor and specialization in project evaluation to dominate joint project evaluation is greatest when $k = 1$.

Next, it is straightforward to prove that \sqrt{q} is always greater than $p^{S^2}(q, k)$, so that if $p^2 \geq q$ holds, then specialization in project evaluation is always preferred to joint evaluation, as we claimed earlier. Interestingly, even if $p^2 < q$, which occurs when there is complementarity in the expertise of the GPs, as we discussed before, specialization in project evaluation can improve organizational performance provided that $p \in (p^{S^2}(q, k), \sqrt{q})$. In Figure 2, we illustrate $p^{S^2}(q, k)$ for different values of k .

 INSERT FIGURE 2

Next, the comparison between $p^{S^2}(q, k)$ and $p^{S^1}(q, k)$ yields the following result:

$$p^{S^2}(q, k) - p^{S^1}(q, k) = \begin{cases} \frac{-k + \sqrt{k^2 + (1-k^2)q}}{1-k} - \frac{(k+1)}{k}q + \frac{2(k+1)}{k^2 X}c & \text{if } k < 1 \\ \frac{4}{X}c - q & \text{if } k = 1 \\ \frac{-1 + \sqrt{1 + (k^2 - 1)q}}{k-1} - (k+1)q + \frac{2(k+1)}{X}c & \text{if } k > 1 \end{cases} \quad (14)$$

When the evaluation cost $c = 0$, $p^{S^2}(q, k) < p^{S^1}(q, k)$ for all k , so that $\phi^{S^2}(q, k) > \phi^{S^1}(q, k)$. Hence, the scope for potential improvement in organizational performance (over joint project evaluation) is greater with specialization in a two-member committee compared with partial evaluation by a single GP.

When c is positive and sufficiently large, it is possible that for some k and q , $p^{S2}(q, k) > p^{S1}(q, k)$, so that $\phi^{S2}(q, k) < \phi^{S1}(q, k)$. In this case, there are situations under which the improvement in expected payoff may be higher with a single GP engaging in partial evaluation than with specialization and division of labor in a two-member committee. In Figure 3, we illustrate the relationship between $p^{S2}(q, k)$ and $p^{S1}(q, k)$ for the case where $k = 0.5$, $c = 2$ and $X = 100$.

 INSERT FIGURE 3

Notice that in this example, partial evaluation by a single GP dominates (is dominated by) specialization in the two-member committee in Region A (B) in Figure 3. In Region C, the condition under which specialization in project evaluation is preferable to partial evaluation by a single GP can be shown to be the following:

$$EV^{S2} > (<) EV^{S1} \text{ if } p > (<) \left\{ \begin{array}{ll} \frac{-k + \sqrt{k^2 + \frac{8(1-k^2)c}{kX}}}{2(1-k)} & \text{if } k < 1 \\ \frac{4}{X}c & \text{if } k = 1 \\ \frac{-1 + \sqrt{1 + \frac{8(k^2-1)c}{X}}}{2(k-1)} & \text{if } k > 1 \end{array} \right. \quad (15)$$

Note that the condition in (15) is independent of q .

2.5 The Optimal Decision Structure

Utilizing the results in (10), (13) and (15), we can determine the optimal decision structure for a specific environment. Firstly, the conditions (p^*, q^*) under which $EV^{S2} = EV^{S1} = EV^T$ can be shown to be

$$\begin{aligned}
p^* &= \frac{-k + \sqrt{k^2 + \frac{8(1-k^2)c}{kX}}}{2(1-k)} \quad \text{and} \quad q^* = \frac{2c}{kX} + \frac{k\sqrt{k^2 + \frac{8(1-k^2)c}{kX}} - k^2}{2(1-k^2)} && \text{if } k < 1 \\
p^* &= q^* = \frac{4}{X}c && \text{if } k = 1 \\
p^* &= \frac{-1 + \sqrt{1 + \frac{8(k^2-1)c}{X}}}{2(k-1)} \quad \text{and} \quad q^* = \frac{2c}{X} + \frac{\sqrt{1 + \frac{8(k^2-1)c}{X}} - 1}{2(k^2-1)} && \text{if } k > 1
\end{aligned}$$

(16).

This leads to the following result.

Proposition 2: When evaluation cost c is positive, p^* and q^* are both decreasing (increasing) in the quality of project, k , for $k < (>) 1$. Therefore, the scope for specialization within a two-member committee to emerge as the optimal decision structure is largest when $k = 1$. When $k \neq 1$, there is greater scope for joint project evaluation to emerge as the optimal decision structure.

In Figure 4, we illustrate the circumstances (p, q) under which partial evaluation by a single GP (Region I), specialization in project evaluation by the two-member committee (Region II), and joint project evaluation (Region III) is the optimal decision structure. When $k \neq 1$ the region III becomes larger so that the scope for joint evaluation increases.

INSERT FIGURE 4

3. VC Expertise and Evaluation Structures

As before, there are several possible types of evaluation processes. Firstly, only one GP may be assigned to evaluate the project to assess its probability of success. The GP may arrive at an opinion after conducting an overall evaluation or just a partial evaluation of one component. Next, both GPs may be assigned to evaluate a separate component of the project, or they may be asked to assess the project's quality independently. In either case, the committee members will communicate their findings and aggregate their opinions to form an overall view regarding the project's probability of success. We shall consider the following four cases:

- S1 One GP assigned to evaluate only one component of the project;
- C1 Both GPs assigned to evaluate a separate component of the project;
- S2 One GP assigned to evaluate the whole project;
- C2 Both GPs assigned to evaluate the whole project independently.

S1 : One manager assigned to evaluate only one component of the project

When GP i ($= 1, 2$) is assigned to evaluate a project component k ($= 1, 2$), he observes a signal \tilde{s}_k^i regarding the quality of component k :

$$\tilde{s}_k^i = \beta_k^i \pi_k + (1 - \beta_k^i) \tilde{u} \quad (19)$$

where \tilde{u} denotes a randomly drawn signal from the uniform distribution over the support $[0, 1]$. Hence, β_k^i is a measure of GP i 's expertise in the evaluation of component k . A higher β_k^i indicates more skilful expertise in the evaluation of component k : if $\beta_k^i = 1$, manager i observes the quality of component k accurately; on

the other hand, if $\beta_k^i = 0$, the GP observes a signal that is completely uncorrelated with the quality of component k .

Based on the signal he observes regarding component k , GP i 's assessment of the project's probability of success is given

$$\theta^{S1}(i, k) \equiv \alpha_k \left[\beta_k^i \pi_k + (1 - \beta_k^i) \tilde{u} \right] + \frac{1}{2} (1 - \alpha_k) \quad (20)$$

Therefore, when GP i is assigned to evaluate component k , his assessment of the expected project payoff is given by $X^{S1}(i, k) \equiv \theta^{S1}(i, k) - \chi$. GP i will recommend accepting projects if $\theta^{S1}(i, k) > \chi$, and reject them otherwise. Let $I(\theta^{S1}(i, k) - \chi)$ denote an indicator function such that $I(\theta^{S1}(i, k) - \chi) = 1$, if $\theta^{S1}(i, k) > \chi$, and 0 otherwise. Conditional on π_1 and π_2 , a project is accepted with probability

$$\text{Prob}(\text{Accept} | S1, \pi_k) = \int I(\theta^{S1}(i, k) - \chi) d\tilde{u} \quad (21)$$

Hence, the expected project payoffs under the decision structure S1 is

$$E[X^{S1}(i, k)] = \iint \left[\int I(\theta^{S1}(i, k) - \chi) d\tilde{u} \right] (\tau(\pi_1, \pi_2) - \chi) d\pi_1 d\pi_2 \quad (22)$$

The problem now is to decide which GP to conduct the partial evaluation and decide on a project component to be evaluated. From (4), it is easy to see that for a given value of π_k , the informativeness of $\theta^{S1}(i, k)$ increases with $\alpha_k \beta_k^i$. Hence, the optimal assignment is based simply on the combination of GP and component that maximizes $\alpha_k \beta_k^i$.

C1: Both GPs assigned to evaluate a separate component of the project

We suppose that GPs communicate their observed signals to arrive at an aggregate assessment regarding the project's probability of success. If GP i is assigned to evaluate component 1, and GP j is assigned to evaluate component 2, the aggregated assessment, denoted $\theta^{C1}(i, j)$, based on the signals \tilde{s}_1^i and \tilde{s}_2^j , is

$$\begin{aligned}\theta^{C1}(i, j) &= \alpha_1 \tilde{s}_1^i + (1 - \alpha_1) \tilde{s}_2^j \\ &= \alpha_1 \left[\beta_1^i \pi_1 + (1 - \beta_1^i) \tilde{u}_i \right] + (1 - \alpha_1) \left[\beta_2^j \pi_2 + (1 - \beta_2^j) \tilde{u}_j \right]\end{aligned}\quad (23)$$

where \tilde{u}_i and \tilde{u}_j are independent. Therefore, the committee's assessment of the expected project payoff is given by $X^{C1}(i, j) \equiv \theta^{C1}(i, j) - \chi$, so that the committee recommends accepting projects if $\theta^{C1}(i, j) > \chi$, and reject them otherwise. We can show that the probability of accepting a project, conditional on π_1 and π_2 , is

$$\text{Prob}(\text{Accept} | C1, \pi_1, \pi_2) = \iint I(\theta^{C1}(i, j) - \chi) d\tilde{u}_1 d\tilde{u}_2 \quad (24)$$

where $I(\theta^{C1}(i, j) - \chi) = 1$ if $\theta^{C1}(i, j) > \chi$ and 0 otherwise. Hence, the expected project payoffs under the decision structure $C1$ is

$$E[X^{C1}(i, j)] = \iint \left[\iint I(\theta^{C1}(i, j) - \chi) d\tilde{u}_1 d\tilde{u}_2 \right] (\tau(\pi_1, \pi_2) - \chi) d\pi_1 d\pi_2 \quad (25)$$

How should GPs be assigned? For a given π_1 and π_2 , it is easy to see from (23) that the informativeness of $\theta^{C1}(i, j)$ is increasing in $\alpha_1 \beta_1^i + (1 - \alpha_1) \beta_2^j$, since the random component carries a smaller weight in the overall assessment of the probability of success. Therefore, GP 1 should be assigned to evaluate component 1, and GP 2 assigned to evaluate component 2 if

$$\alpha_1 \beta_1^1 + (1 - \alpha_1) \beta_2^2 > \alpha_1 \beta_1^2 + (1 - \alpha_1) \beta_2^1 \quad (26)$$

S2 : Both GPs assigned to evaluate a separate component of the project

Under this decision structure, only one GP is assigned to evaluate the overall quality of the project. GP i 's 'generalist' expertise is given by a measure

$$\gamma_i \equiv \alpha_1 \beta_1^i + (1 - \alpha_1) \beta_2^i \quad (27)$$

His assessment of the probability of success of the project is given by $\theta^{S2}(i)$:

$$\theta^{S2}(i) = \gamma_i p(\pi_1, \pi_2) + (1 - \gamma_i) \tilde{u} \quad (28)$$

$$= \left[\alpha_1 \beta_1^i + (1 - \alpha_1) \beta_2^i \right] (\alpha_1 \pi_1 + (1 - \alpha_1) \pi_2) + \left[1 - \alpha_1 \beta_1^i - (1 - \alpha_1) \beta_2^i \right] \tilde{u}$$

Given GP i 's overall evaluation, his assessment of the expected payoff is given by $X^{S2}(i) \equiv \theta^{S2}(i) - \chi$. GP i will recommend accepting projects if $\theta^{S2}(i) > \chi$, and

reject them otherwise. The probability of accepting a project, conditional on π_1 and π_2 , is

$$\text{Prob}(\text{Accept} | S2, \pi_1, \pi_2) = \int I(\theta^{S2}(i) - \chi) d\tilde{u} \quad (29)$$

where $I(\theta^{S2}(i) - \chi) = 1$ if $\theta^{S2}(i) > \chi$, and 0 otherwise. Hence, the expected project payoffs under the decision structure S2 is

$$E[X^{S2}(i)] = \iint \left\{ \left[\int I(\theta^{S2}(i) - \chi) d\tilde{u} \right] (p(\pi_1, \pi_2) - \chi) \right\} d\pi_1 d\pi_2 \quad (30)$$

Clearly, for decision structure S2, the GP with the highest generalist expertise γ_i should be assigned to conduct an overall evaluation of the project in this case.

C2: Both GPs assigned to evaluate the whole project independently

Finally, we consider the case where both GPs are assigned to conduct an overall evaluation of the project. The GPs' assessments are given by

$$\theta^{S2}(1) = \left[\alpha_1 \beta_1^1 + (1 - \alpha_1) \beta_2^1 \right] (\alpha_1 \pi_1 + (1 - \alpha_1) \pi_2) + \left[1 - \alpha_1 \beta_1^1 - (1 - \alpha_1) \beta_2^1 \right] \tilde{u}_1 \quad (31)$$

$$\theta^{S2}(2) = \left[\alpha_1 \beta_1^2 + (1 - \alpha_1) \beta_2^2 \right] (\alpha_1 \pi_1 + (1 - \alpha_1) \pi_2) + \left[1 - \alpha_1 \beta_1^2 - (1 - \alpha_1) \beta_2^2 \right] \tilde{u}_2$$

where \tilde{u}_1 and \tilde{u}_2 are independent. The following rule is used by the committee to aggregate the information and to arrive at an overall assessment of the probability of success.

$$\theta^{C2} = \frac{\gamma_1}{\gamma_1 + \gamma_2} \theta^{S2}(1) + \frac{\gamma_2}{\gamma_1 + \gamma_2} \theta^{S2}(2) \quad (32)$$

In other words, the overall assessment θ^{C2} is a weighted assessment of the opinion of both GPs, where the weights are based on the 'generalist' skills of each GP. A venture capitalist with higher generalist skills commands a larger weight in the overall assessment. The committee's assessment of the expected project payoff is given by

$X^{C2} \equiv \theta^{C2} - \chi$. Hence, projects will be accepted by the committee if $\theta^{C2} > \chi$, and rejected otherwise. The probability of accepting a project, conditional on π_1 and π_2 , is

$$\text{Prob}(\text{Accept} | C2, \pi_1, \pi_2) = \iint I(\theta^{C2} - \chi) d\tilde{u}_1 d\tilde{u}_2 \quad (33)$$

where $I(\theta^{C2} - \chi) = 1$ if $\theta^{C2} > \chi$ and 0 otherwise. Hence, the expected project payoffs under the decision structure $C2$ is

$$E[X^{C2}] = \iint \left\{ \left[\iint I(\theta^{C2} - \chi) d\tilde{u}_1 d\tilde{u}_2 \right] (p(\pi_1, \pi_2) - \chi) \right\} d\pi_1 d\pi_2 \quad (34)$$

The expertise of the committee is increasing in both γ_1 and γ_2 .

3.2 Optimal Decision Structure: Comparative and Absolute Advantages

We are ready to analyze the circumstances under the different decision structures emerge as optimal decision structures. As it is, the optimal decision structure depends on several dimensions of the investment environment and venture capitalist's abilities. To keep the analysis tractable, we shall assume, without loss of generality, that $\chi = 0.5$. We employ the following specification for the matrix of venture capitalist's skills as defined by β_k^i ; $i, k = 1, 2$.

$$\begin{bmatrix} \beta_1^1 & \beta_2^1 \\ \beta_1^2 & \beta_2^2 \end{bmatrix} = \begin{bmatrix} 1-\delta & \delta \\ \phi & \phi \end{bmatrix} \quad (35)$$

where $\delta \in [0,1]$ and $\phi \in [0,1]$. We note that

$$\frac{\beta_1^1}{\beta_2^1} - \frac{\beta_1^2}{\beta_2^2} = \frac{1-\delta}{\delta} - 1 > (<) 0 \text{ if } \delta < (>) \frac{1}{2} \quad (36)$$

Hence, δ is a measure of the *comparative advantage* of venture capitalist's skill.

When $\delta < 0.5$, GP 1 has comparative advantage in evaluating component 1 while GP 2 has comparative advantage in evaluating component 2. When $\delta > 0.5$, the comparative

advantage is reversed; GP 2 has a comparative advantage in evaluating component 1 while GP 1 has a comparative advantage in evaluating component 2.

The comparative advantage of GPs is an important factor in their assignment in decision structure CI , where each GP is tasked to evaluate a different project component. However, from our earlier discussion, the assignment of GPs is not based simply on comparative advantages. It is also dependent on the weights of the components in determining the overall probability of success of the project. From the condition in (26), and using the current parameterization in (35), GP 1 should be assigned to component 1 and GP 2 assigned to component 2 if the condition for α_1 holds:

$$\alpha_1 \begin{cases} > \frac{\delta - \phi}{1 - 2\phi} & \text{if } \phi < \frac{1}{2} \\ < \frac{\delta - \phi}{1 - 2\phi} & \text{if } \phi > \frac{1}{2} \end{cases} \quad (37)$$

Otherwise, the assignment is reversed.

Next, if $\phi < \text{Min} [1 - \delta, \delta]$, then GP 1 has an *absolute advantage* in the evaluation of both components. In this case, GP 1 should be assigned in evaluation processes involving just one manager – i.e. $S1$ and $S2$. However, if $\phi > \text{Max} [1 - \delta, \delta]$, then GP 2 has an absolute advantage over GP 1, and will be chosen under $S1$ and $S2$.

Under the current specification, the optimal decision structure is a function of three variables, ϕ , δ and α_1 . Figure 5 illustrates the different regions where GPs possess different absolute and comparative advantages.

 INSERT FIGURE 5 HERE

For each configuration of the parameters, we compute the expected project payoffs under each of the four decision structures and select the decision structure that generates the highest expected payoff. We shall consider six cases, where $\alpha_1 = 0, 0.1, 0.2, 0.3, 0.4$ and 0.5 . We do not have to consider the cases where $\alpha_1 > 0.5$, since the analysis is symmetric about $\alpha_1 = 0.5$ in our model. Figure 6 presents the results.

INSERT FIGURE 6 HERE

There are several interesting results. Firstly, the scope for specialization in information production of investment project evaluation (CI) is increasing in α_1 , judging by the areas under which the different decision structures emerge as the optimal ones. When $\alpha_1 = 0.5$, both project components are equally important in determining the overall probability of success of the project, the combined scope for partial evaluation (SI) or specialization by both managers (CI) to exist as optimal decision processes is greater than that for structures ($S2$ and $C2$) which require overall evaluation.

In the limit when $\alpha_1 = 0$, only component 2 matters in determining the overall probability of success of the project. In this case, the decision structures SI , $S2$ and CI are clearly equivalent. Therefore, the choice is basically between assigning one venture capitalist to evaluate the project and getting both venture capitalists to evaluate the project. Intuitively, one would have expected that a two-member committee ($C2$) evaluation process to always dominate just having one GP to screen the projects ($S2$). It turns out not to be the case.

Having both GPs evaluate the project does not always improve organizational performance in terms of the expected project payoffs. The intuition is as follows.

First, notice that when ϕ is close to δ , i.e. when both GPs are similarly skilled in evaluating component 2 (the only component that matters here), the optimal decision structure is *C2*. However, if one GP is better skilled, either low ϕ and high δ , or vice versa, then the optimal decision structure is to use only one GP (i.e. *S2*). Adding a less skilled GP to the evaluation process does not improve the informativeness of the evaluation process.

Comparing Figures 5 and 6, we notice that the regions where *C1* emerge as the optimal decision structure occur in Regions B and E in Figure 1. These are the cases where each GP has comparative and absolute advantage in the evaluation of a different project component. Hence, it is natural that the decision structure for project evaluation with specialization will most likely emerge as the optimal decision structure.

4. Conclusion

Our study focuses on the case where venture capitalists are fallible in the sense that they may not always observe the true value of project or project components under assessment. We present a model of specialized expertise in staged decision making. In the model, specialized expertise is related to skills in observing the true quality of a project component. We show that although specialization in VC decision-making is not unambiguously attractive in all circumstances, there exists a range of circumstances under which staged project evaluation with one manager or specialization in project evaluation in a two-member committee can improve organizational performance. Our theory helps explain why sometime VCs engage in staged investment while other times they do not.

The analysis reported here represents an initial effort to investigate an aspect of collective decision-making, e.g., venture capitalist staged investment. Such joint information screening process is important to venture investment decision. In our study, we consider only the case where venture capitalists share a common organizational objective, which is to maximize the expected project payoffs. When they have divergent interests, this might change the scope for strategic behavior in VC syndication and staged investment. Further research is called on to understand this question.

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Figure 1: Partial Project Evaluation with One VC

$$p^{S1}(q,k) \equiv \frac{q(k+1)}{\text{Min}[1,k]}, \text{ with } c = 0$$

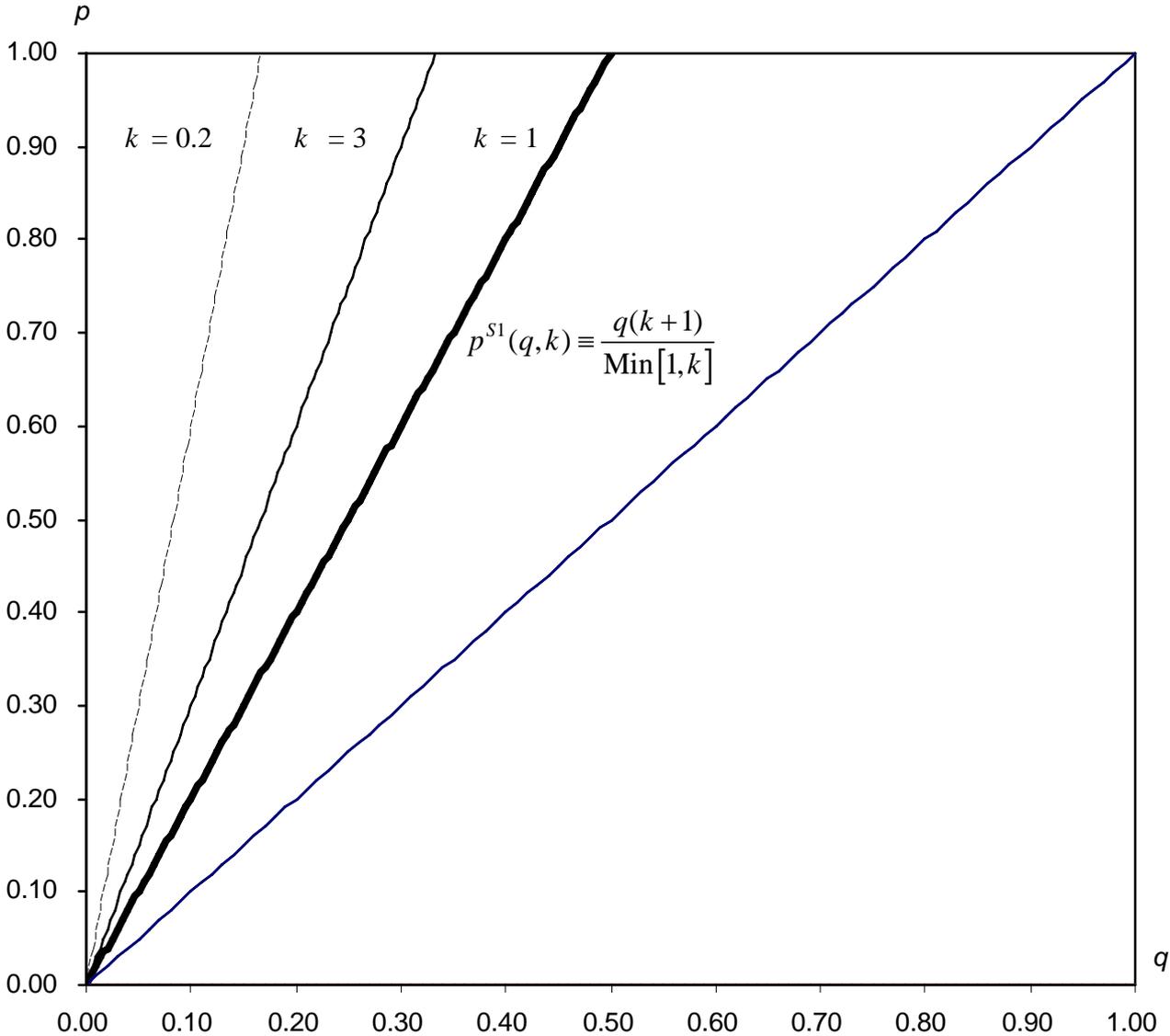


Figure 2: Specialized Project Evaluation with Two VCs

Illustration of $p^{S^2}(q,k)$ for selected values of k

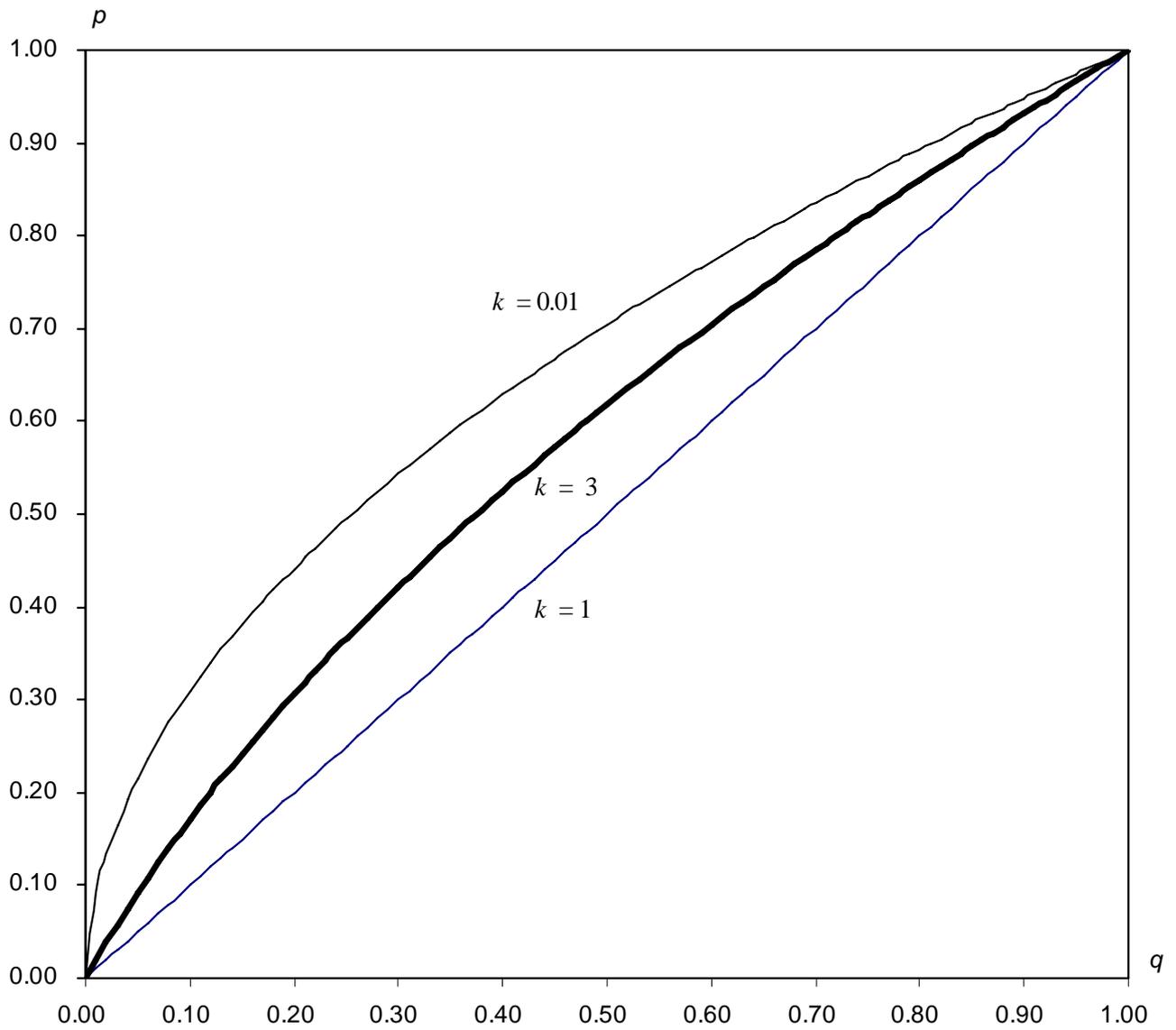
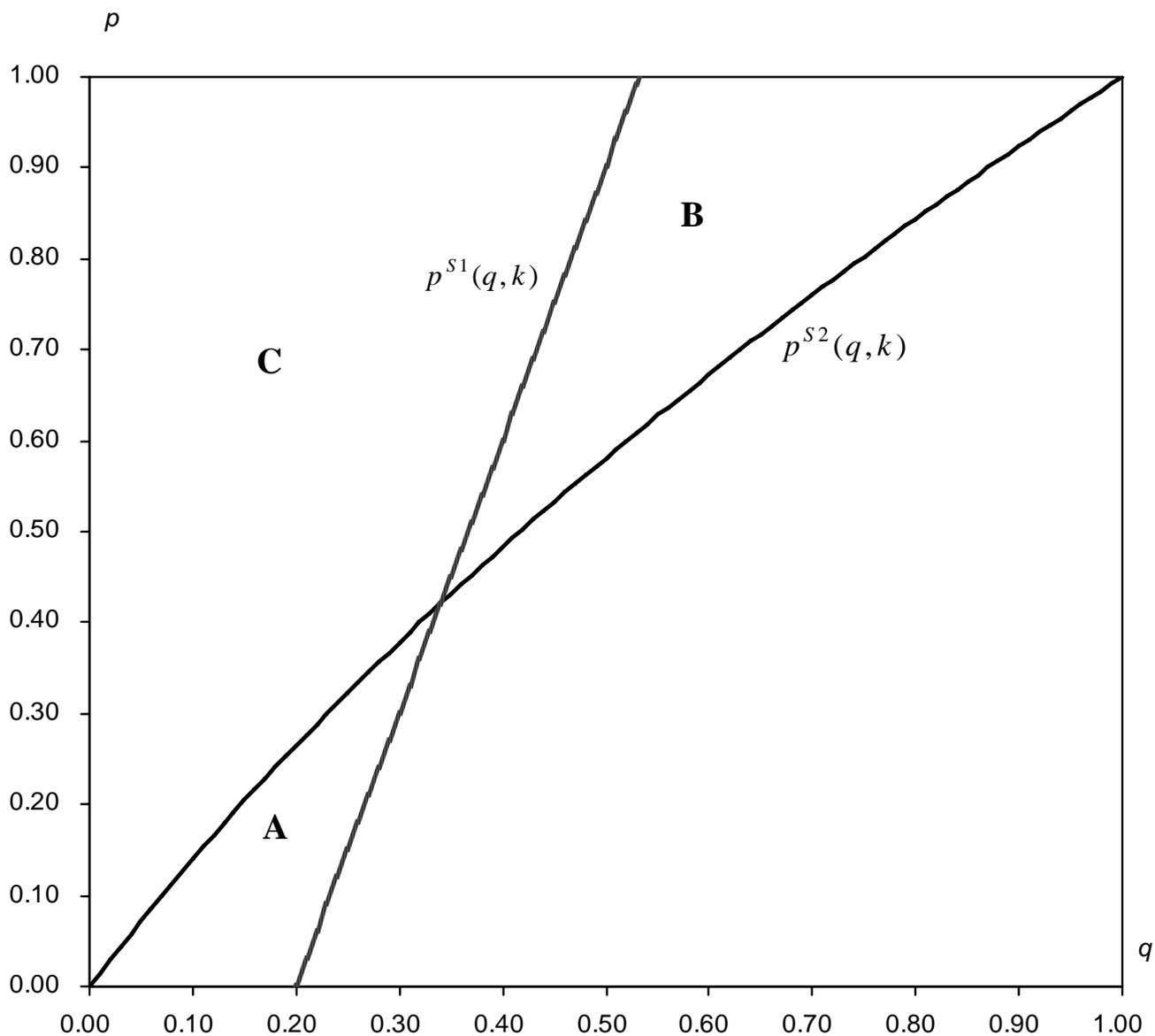


Figure 3: Scope for Partial Project Evaluation versus Specialization in VCs

Comparison of $p^{S1}(q,k)$ and $p^{S2}(q,k)$ for $k = 0.5$, and $c = 2$ and $X = 100$

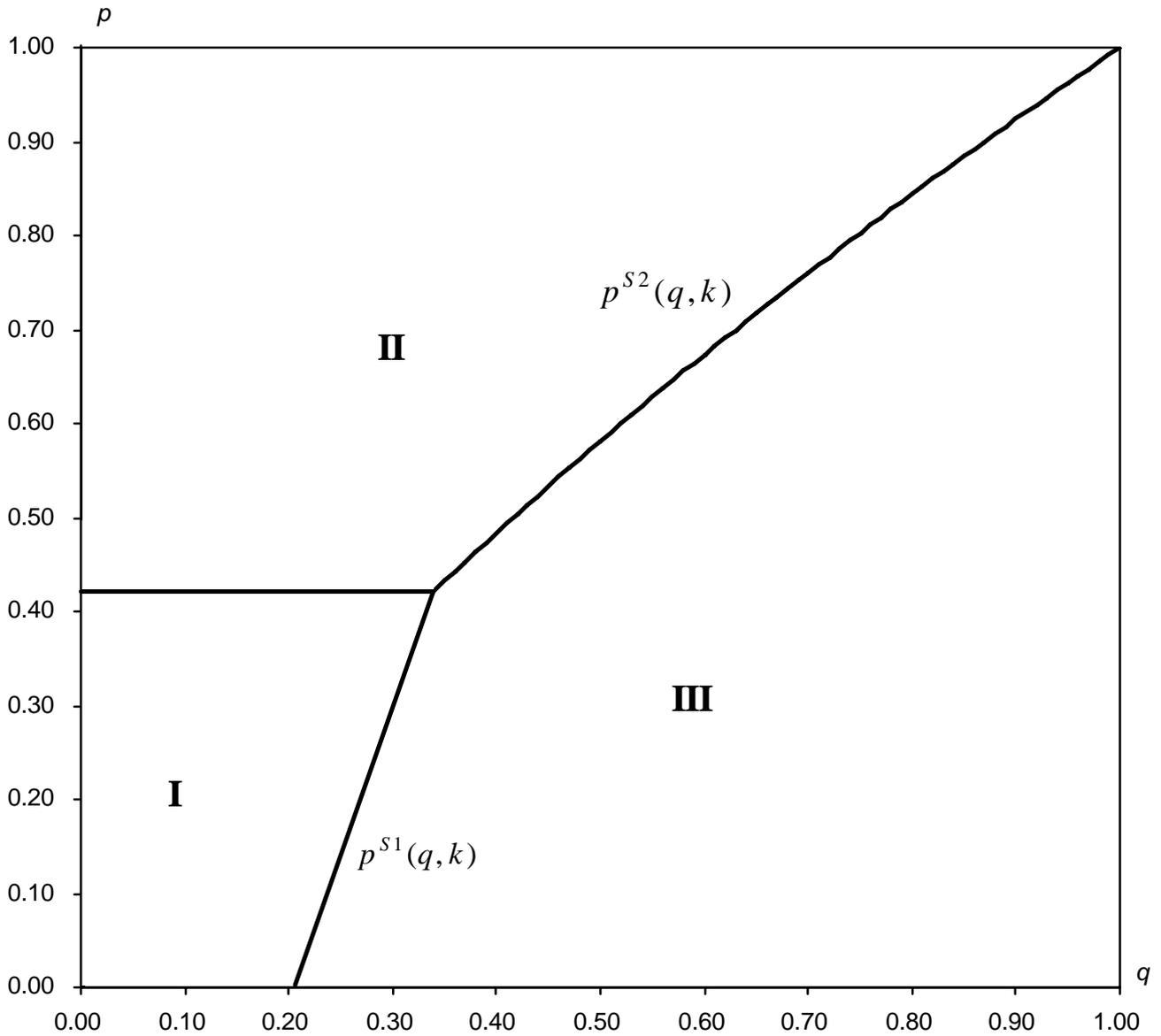


Region A: Partial evaluation by a single VC dominates specialization by 2 VCs.

Region B: Specialization by 2 VCs dominates partial evaluation by 1 VC.

Figure 4: Scope for Specialization in VC Investment

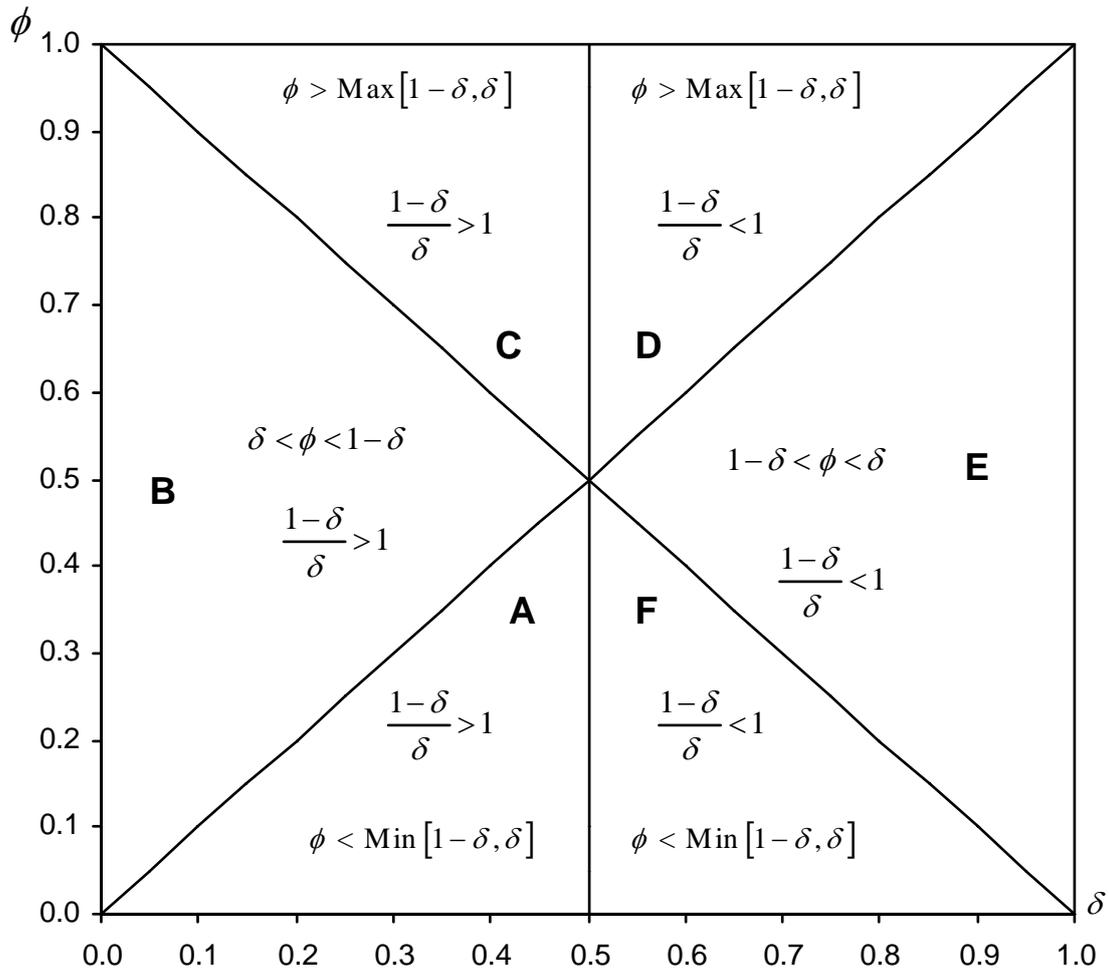
Illustration for the case $k = 0.5$, and $c = 2$ and $X = 100$



The optimal decision architecture is as follows:

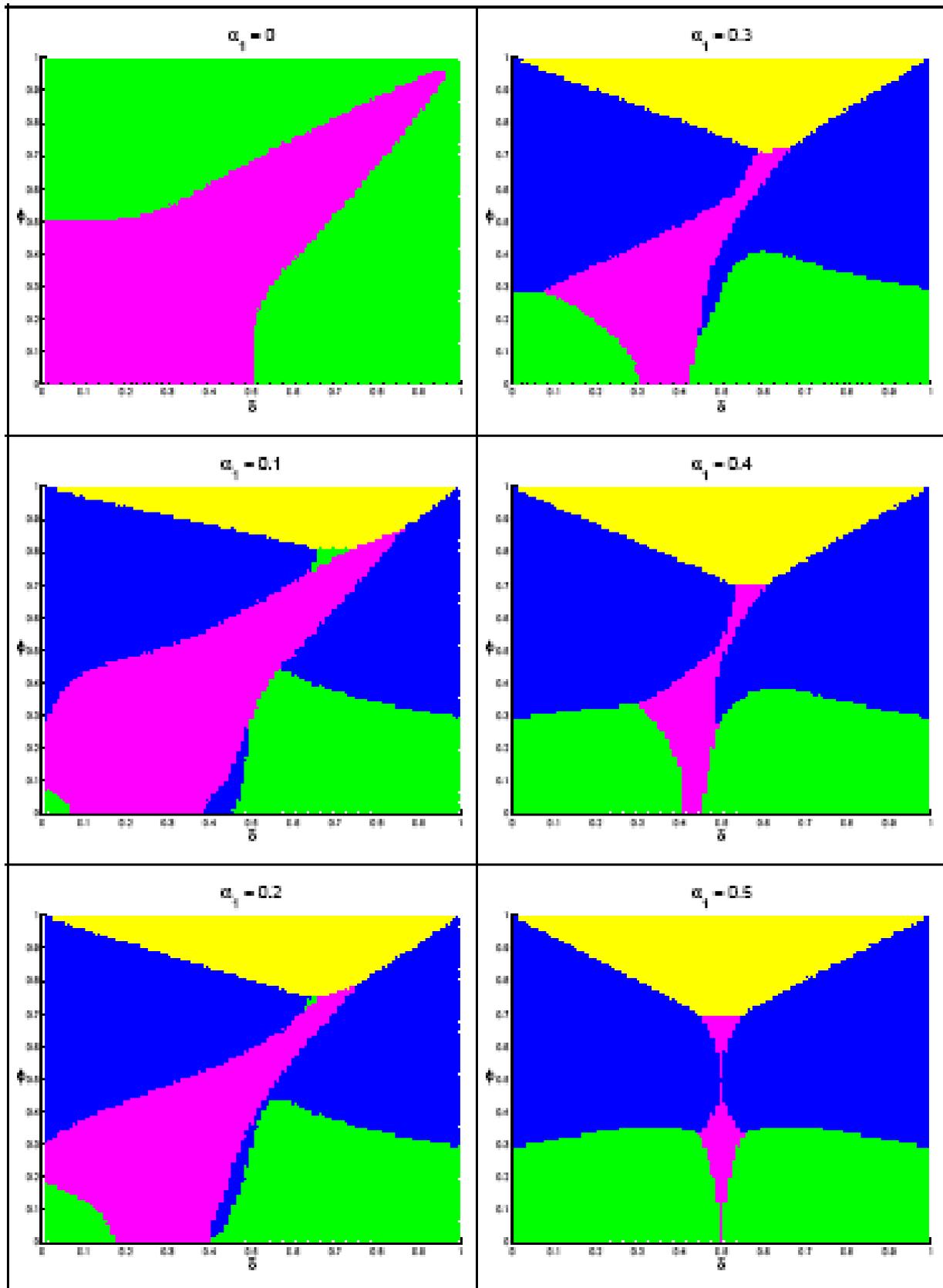
- Region I: Partial evaluation by 1 VC.
- Region II: Specialization in project evaluation by 2 VCs.
- Region III: Joint project evaluation by 2 VCs.

Figure 5: Managerial Expertise



- A: VC 1 has absolute advantage in both components and comparative advantage in component 1. VC 2 has comparative advantage in component 2.
- B: VC 1 had comparative and absolute advantage in component 1 and VC 2 has comparative and absolute advantage in component 2.
- C: VC 2 has absolute advantage in both components and comparative advantage in component 2. VC 1 has comparative advantage in 1.
- D: VC 2 has absolute advantage in both components and comparative advantage in component 1. VC 1 has comparative advantage in 2.
- E: VC 1 had comparative and absolute advantage in component 2 and VC 2 has comparative and absolute advantage in component 1.
- F: VC 1 has absolute advantage in both components and comparative advantage in component 2. VC 2 has comparative advantage in component 1.

Figure 6: Optimal Evaluation Structures



Legend: Green (S1), Yellow (S2), Blue (C1), Magenta (C2)

Appendix: **Model Scenario II: Absolute and Relative Advantage in Specialized Expertise**

In this section, we explore the issue of absolute advantage and relative advantage in specialized decision-making of VC investment. For our purpose, we simplify the model by assuming that successful project yields a payoff of $X = x_h > 0$, while an unsuccessful project yields a payoff of $X = -x_l < 0$. Potential projects differ in their probability of success $\tau \in [0, 1]$, and is drawn from a known distribution function to be defined shortly.

Again, there are two components that are critical for the success of each project. Formally, let $\tau \equiv \tau(\pi_1, \pi_2)$, where π_k is a measure of the quality of component k ($= 1, 2$). For simplicity, we suppose that π_k is uniformly distributed over the support $[0, 1]$, and that

$$\tau(\pi_1, \pi_2) = \alpha_1 \pi_1 + \alpha_2 \pi_2, \quad \alpha_1 + \alpha_2 = 1, \quad \alpha_k \in [0, 1], k = 1, 2 \quad (17)$$

The probability of success of a project is simply a weighted average of the qualities of the project components, where the weights determine their relative importance. Next, let

$$\chi \equiv \frac{x_l}{x_h + x_l} \quad (18),$$

so that the expected payoff of a project, $\tau x_h - (1 - \tau)x_l$, is positive (negative) if $\tau > (<)$ χ . Since a larger x_h or a smaller x_l reduces χ , a smaller χ is an indicator of a more favorable investment environment. For simplicity, we normalize $(x_h + x_l)$ to unity, so that $\chi = x_l$.

The actual quality of each project is unobservable *ex-ante*, so that all projects are indistinguishable and has an unconditional expected probability of success of $E[\tau] = 0.5$. The unconditional expected payoff is $E[X] =$

$\iint \{ \tau(\pi_1, \pi_2)x_h - [1 - \tau(\pi_1, \pi_2)]x_l \} d\pi_1 d\pi_2 = 0.5 - \chi$. Thus, with no evaluation, projects should be accepted (rejected) if $\chi < (>) 0.5$.