Innovation Interdependence and Investment Choices:

An Experimental Approach to Decision Making in Ecosystems

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Abstract: We explore how decision makers perceive and assess the level of risk arising in interdependent settings that characterize innovation ecosystems. In a series of four stylized experiments, we examine the way in which the presence of required partner co-innovations impact how individuals set expectations for their own innovation investments. We find that opportunities characterized by greater interdependence – e.g., a greater number of participating partners – leave individuals subjectively more confident and optimistic than equivalent situations with less interdependence. Our study elaborates on the biased assessment of conjunctive events (Bar-Hillel, 1973) and explores the effects of the presentation of interdependence on a number of key decisions: project valuation and "green-lighting" decisions; project composition, and choice of the number of partners. We also consider how task structure may improve judgment by separating the assessment of risk from the assessment of value. We conduct our study with a wide range of participant samples ranging from undergraduates to senior executives. Collectively our findings hold important implications for the ways in which individuals, organizations, and policymakers approach and assess their innovation choices.

Introduction

Confronted with ever increasing pressures to grow, and enabled by improvements in information and communication technologies, organizations across the economic spectrum are increasingly turning to collaboration to meet their goals (Powell et.al.1996; Hansen, Gulati et.al, 2012). Collaboration is attractive because, by aggregating their resources and capabilities, individuals, teams and organizations can often accomplish more together than they can individually.

In the context of innovation, collaboration has become increasingly important as firms shift from autonomous innovations, in which their individual efforts and products create stand-alone value, to ecosystem innovations, in which their value propositions depend on a collection of pieces coming together successfully (Moore, 1996; Iansiti and Leiven, 2004; Adner, 2013).

The flip-side of collaboration, however, is interdependence. As organizations increasingly rely on partners to contribute to a collective effort, the success of the collective effort becomes reliant on successful execution by a growing number of independent partners.

Consider, for example, the expectations surrounding the rise of 3G telephony and its promise of internet enabled mobile services such as real time videos, mobile payments, and workforce productivity applications. In 2000, Nokia forecasted that by 2002 more than 300 million handsets would be connected to the mobile internet to take advantage of such enhanced services. This expectation informed both their public commitments, strategic priorities, and the urgency of their internal development efforts. Nokia and the other handset makers were ready with 3G handsets in 2002, but the actual number of 3G handsets in service that year was a mere 3 million, 100 times less than forecasted. Despite support, enthusiasm, and investment by all the participants, delays in the availability of co-innovations such as location based services, secure mobile payment systems, and enterprise mobile applications meant that, despite the availability

of 3G handsets, the promised 3G value proposition could not be enacted in the expected time frame. Over time, the requisite co-innovations did emerge, and the $300 million target was reached in 2008. The six year delay, however, meant that commitments and investments made according to the initial expectations were compromised (see Adner, 2013).

The rise of interdependent innovation raises a critical question for organizations and their decision makers: in making commitments to uncertain innovations, do managers effectively account for the risk that arises from dependence on partners? The Nokia example illustrates decision making in an interdependent setting characterized by compound probabilities, where success is a conjunctive event that depends on the successful development of each of the individual components. Nokia was well aware of its dependence on co-innovators. However, while its expectations for its own readiness to deliver a 3G handset by 2002 were correct, Nokia overestimated the likelihood that the collective group of co-innovators that comprised its ecosystem would be ready to deliver the complete value proposition by the 2002 deadline.

We draw a distinction between awareness and perception of dependence. Awareness of dependence is about knowing who one's critical partners are. Perception of dependence is conditional on awareness and is about integrating the knowledge of dependence into an assessment of the overall opportunity. This distinction is reflected in the difference between Nokia being aware of its critical co-innovators and Nokia having an objective assessment of the likelihood of success given its own probabilities and those of its critical co-innovators. Even with complete awareness of the partners on which one depends, a manager may misperceive the likelihood of success for the venture as a whole.

In this paper, we explore how the perception of dependence affects decision-making. In a series of four experiments in which participants have perfect awareness of dependence, we examine how the presence of required co-innovations affects the perception of dependence and

biases how individuals set expectations. We show that this bias arises from the presentation of dependence (showing the probabilities for individual components rather than the overall project) and the extent of dependence (increasing the number of participating critical partners). We find that an opportunity characterized with more dependence leaves individuals subjectively more confident and optimistic than an equivalent opportunity characterized with less dependence.

We explore how the perception of dependence impacts a number of key decisions: project valuation and "green-lighting"; project composition; and choice of the number of partners. We also explore the possibility of improving judgment through alternative task design: separating the assessment of risk from the valuation of the investment opportunity. We conduct our study with a wide range of participant samples ranging from undergraduates to senior executives. Collectively our finding of a systematic bias towards overoptimism when dependent on partners – even when only considering risk perceptions – has clear implications for innovation management and organization design.

We examine these dynamics by studying a specific case of interdependence in a venture: when multiple partners all need to succeed in order for the venture to deliver on its value proposition which is otherwise is valueless. The setting of the judgments and decisions in our experiments is one in which successful achievement of a value proposition depends on successful execution by multiple interdependent partners. The behavior we examine is from the perspective of one decision-maker in such a setting. Therefore, we examine the perspective of the managers at a focal firm as they assess and manage their dependence on partners. Although the characteristics of this case can be relaxed, it serves as a useful benchmark for isolating the effects of the perception of the conjunctive likelihood for the venture as whole. In the general discussion, we will address how this case can be further expanded upon.

Innovation, interdependence, and perceptions of risk

The innovation literature has had a long appreciation of interdependence in the context of systems of technology. A plethora of rich historical studies, from Rosenberg's (1976) insights into the technical imbalances that guided the evolution of the machines tool industry, to Hughes's (1983) study of the development electrical power system, to Bresnahan et.al.'s (1996) examination of the role of co-invention in guiding progress in the computer industry, have explored the ways in which bottlenecks and imbalances across the technology frontier have critically shaped the trajectories of innovations that rely on other innovations to create their value. The emergent research stream on innovation ecosystems (e.g., Moore, 1996; Iansiti and Leiven, 2004; Adner and Kapoor, 2010, 2015; Kapoor and Furr, 2015) examines firm strategies in designing and managing such interdependent systems, as do game theoretic approaches to managing collaboration in ecosystem contexts (e.g., Feng and Lui, 2014; Mantovani and Ruiz-Aliseda, Forthcoming). Throughout this stream, however, the standard underlying assumption is that firms and managers have and use objective knowledge of interdependence. As such, the role of risk perception at the level of individual decision makers, and the potential role of subjectivity in risk assessment, has been largely neglected.

Interdependence – mutual impact among parties on their ability to create value – has similarly been a central theme in the organizations literature since its inception (e.g., Smith, 1776; Weber, 1947; Thompson, 1967; Lawrence and Lorsch, 1967). Research in this vein has yielded great insight into how to consider and address interdependence challenges that arise from problems of coordination (e.g., Galbraith, 1977); culture compatibility (Schein, 1992); power asymmetries (Salancik and Pfeffer, 1978); task uncertainty (Tushman and Nadler, 1978); and information flow (Puranam et al. 2012). The goal of this stream has been to identify productive approaches to managing interdependence.

As is the case in the innovation literature, the question of perception of aggregate risk has been largely absent from these discussions. While there is increasing attention to the role of perception as regards task division and task allocation (Raveendran et al. 2015), the role of perception regarding how managers aggregate divided tasks in their decision-making process has received comparably little attention.

The way in which managers perceive the aggregation of interdependent tasks matters because the very choice of creating interdependence gives rise to compounding risk. Introducing this interdependence creates the risk that even if a focal party can succeed in accomplishing its task, its value will be hampered by failure on the part of its partner. Assessing collaborative risk is thus a foundational component of managing collaboration; and correctly perceiving collaborative risk is a foundational component of correct assessment. Thus, by explicating the potential for subjectivity in the perception of dependence on partners, our study contributes to the literatures' goal of more productive assessment and management of interdependence.

We introduce a behavioral decision making lens to the question of managing interdependence in innovation. Research in psychology on conjunctive events has examined how individuals aggregate the likelihood of separate events and perceive the overall likelihood of the conjunctive set. The prominent example in this literature is Bar-Hillel (1973) who argued that "the subjective probabilities of compound events are systematically biased in the direction of their components, resulting in the over estimation of the likelihood of conjunctive events" (1973, p. 396).[1] The notion that individuals tend to overestimate the likelihood of conjunctive events is

[1] Bar-Hillel's work and our study are distinct from the much larger stream of research on the *conjunction fallacy*. The conjunction fallacy is a violation of the following law of probability: the probability of a conjunction, P(A&B), cannot be greater than the probability of the individual components P(A) and P(B). Research on the conjunction fallacy has studied psychological categorization: an assessment of whether a person or thing belongs to a given category. Much of it has been around the now classic 'Linda problem.' In it, Linda is described as being "concerned with issues of discrimination and social justice" and participants are asked to assess the likelihood that she fits in various categories. The key finding is that participants assess the likelihood that Linda "is a bank teller and active in

now taken as assumed in the field of judgment and decision-making and is often included in reviews of cognitive biases (Bazerman and Moore 2012; Tversky and Kahnemen 1974; Kahneman 2011), although these reviews almost exclusively point back to Bar-Hillel's (1973) single seminal paper.

Bar-Hillel (1973) presented two experiments involving conjunctive events, both with a subject pool of high school and college students in Israel. To provide a sense of these experiments, we will describe the first here in detail. Participants were faced with choices between a single-shot gamble and a sequential compound gamble. The single-shot gamble involved drawing one marble from an urn of 20 marbles, of which x were "good" red marbles and $20 - x$ were "bad" white marbles. For the compound gamble, there were more "good" marbles in the urn (i.e., a higher x) but one would need to repeatedly draw a marble with replacement to a predetermined maximum of y draws; if at any stage a "bad" marble was drawn, then the process was discontinued. The single-shot x and the compound gamble x and y were selected for each pair of gambles such that the expected value for each was approximately equal. For example, participants needed to choose between (i) a single-shot gamble in which 8 of the 20 marbles in the urn were "good" red marbles and (ii) a compound gamble in which 18 of 20 marbles in the urn were "good" red marbles but nine sequential draws needed to come up red. Seventy-five students each made four such choices with the following result: 60% of the time they preferred the compound gamble instead of the single-shot gamble, when, theoretically, one would expect a 50% rate given the roughly equal expected values.

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the feminist movement" as higher than the likelihood that Linda "is a bank teller" (Tversky and Kahneman 1983, pg. 297), a violation of probability theory. This bias has been shown to arise due to the use of 'representativeness' and 'associative thinking' in the formation of category likelihood judgements; the first category better fits the description of Linda so individuals believe she is more likely to fall in that category. The vast majority of studies of the perception of conjunctive events have examined this question of categorization under uncertainty. The conjunction fallacy and questions of categorization play no role in our study.

A deeper search in the cognitive psychology literature reveals a similar finding by Slovic (1969) in his exploration of how to make a gamble more or less appealing while holding its expected value constant. In related work, other cognitive psychologists have focused on testing the internal consistency of judgments of the probability of events, conditional probabilities of those events, their intersection, and their union (Peterson et al. 1965; Wyer 1976; Khemlani, Lotstein and Johnson-Laird 2014; see also Budescu and Fischer 2001).

In this paper, we build on Bar-Hillel's classic hypothesis and explore its implications for interdependent innovations. To illustrate the importance of the perception of conjunctive events in an innovation context, consider the following two meetings. In meeting A, five partners are discussing the attractiveness of a potential collaboration. All five have aligned interests and commit to assigning their best resources to their respective tasks. Further, each of them has high expectations for completing their task: each of the five assesses that they have an 85 percent chance of successfully developing their particular component by the deadline.

Meeting B is largely identical: five partners are discussing the attractiveness of a potential collaboration and similarly express a willingness to commit their best effort to their respective task. But rather than offering their independent probabilities of successful development, they discuss the aggregate chance that *all five* will be able to deliver their necessary part within one year: 44 percent.

Which group do you think is more likely to pursue this venture? Which group do you expect to be more optimistic about the venture's success? Any predicted difference should be surprising because the two innovative ventures have identical chances of achieving overall success: $.85^5 = .44$. However, we have found that individuals typically anticipate much greater optimism about the joint venture in meeting A. Such a pattern would be consistent with the underlying logic presented in Bar-Hillel's (1973) paper. Conjunctive events have an inherent,

important structural feature: the separate probability that any one event will be successful is *always* greater than the aggregate probability that all separate events will be successful. That is, given the nature of probability, the likelihood of the sub-events in question will always be higher than the likelihood of the conjunctive event. Therefore, one will be more confident in the chances of success for the sub-event than for the conjunctive event.

Affect is the initial, intuitive feeling of positivity or negativity that emerges when faced with a stimulus (Slovic and Peters 2006). Slovic and colleagues have used the term *affect heuristic* to characterize the use of these intuitive feelings, often non-consciously, as information to guide judgment and decision-making (Slovic et al. 2002). Numerous studies have shown that people rely on intuitive feelings as information when they form perceptions of risk (see Loewenstein et al. 2011; Rottenstreich and Hsee 2001). This past research suggests that, in the context of conjunctive events, because the sub-events have a higher probability than the conjunctive event, forming an optimistic intuitive impression of the sub-events may yield a carry-over effect of optimism regarding the likelihood of the conjunctive event. In other words, if seeing the higher probabilities of the separate sub-events has an incidental effect on perception of the conjunctive event (Bar-Hillel 1973), then in situations of interdependence individuals are likely to be overly optimistic about the prospects of the entire venture coming together.

Such overoptimism will manifest itself in behavior that appears overconfident. Past work on overconfidence has studied contexts of ambiguity and documented human tendencies to overestimate (i) one's ability to execute (e.g., planning fallacy), (ii) one's ability relative to others' (e.g., the Lake Wobegon effect), and (iii) accuracy of one's predictions (e.g., overly narrow confidence intervals; Moore & Healy 2008; Soll & Klayman 2004). In our study, the decisions arise in contexts where there is no ambiguity: participants have full awareness of the exact number of partners, each partner's exact probability of success, and the exact potential

payoff of the alternative ventures from which they can choose. By eliminating these factors, our study hones in on the effect of the perception of risk as one faces dependence on partners.

In Experiment 1, we re-establish Bar-Hillel's finding in a more straight forward context and then use that as the starting point for our examination of the perception of interdependence. Our objective is to hone in on the consequences of interdependence and interdependent framing for managerial judgment and decision making. To this end we present a panel of online managers with one of two equivalent investment choices and ask them to value the projects: the first is characterized by an aggregate probability of success (10.5%) and the second presented as separate independent probabilities of critical component innovations (70%, 50%, and 30%). Participants reported a higher willingness-to-pay (WTP) for the opportunity when presented with the separate probabilities than when presented with the aggregate probability.

In Experiment 2, conducted with business executives, we consider the effect of the number of partners on subjective confidence and project valuation. The participants were presented with one of two potential projects: the first depended on the successful completion of two co-innovations with an independent 45% chance of success for each, and the second depended on six co-innovations with an independent 75% chance of success for each. The executives reported higher confidence and WTP for the six-party venture than the two-party venture which is counter to the expected values of the ventures.

In Experiment 3, we examine how the presentation of interdependence affects the number of critical partners individuals opt to include in a project. Participants were asked to choose the number of partners to include in a project, with higher real potential payments and greater risk associated with a larger number of partners. Half of the sample was presented with the payoff schedule and an aggregate probability value, while the other half was presented with the same payoff schedule and the separate independent chance of success for each additional partner.

When the independent probability for each additional potential partner is observed, individuals opt for significantly riskier project designs than when the options are presented with aggregate probabilities visible. This occurred even when participants were reminded to multiply probabilities when faced with a conjunctive event.

In Experiment 4, we show how alternative task design can mitigate the bias towards optimism when facing dependence on partners. It first reveals that having an individual explicitly estimate the aggregate chance of venture success is not sufficient to mitigate the bias. However, when the task of risk assessment and the task of opportunity valuation are divided across two different individuals, overoptimism in the opportunity is significantly reduced and valuations are better calibrated.

Our empirical approach

A fair criticism of stylized experiments is that they omit the richness of a true organizational context. Real-world managerial decisions are influenced by many contextual factors at once, the majority of which are ignored by any single stylized task. Therefore, the generalizability of results from stylized experiments should not be assumed until the phenomenon can be rigorously documented "in the wild." Although our study is motivated by real-world examples (Adner 2006, 2013), the limitations on generalizability from stylized experiments certainly apply.

However, there is also considerable value in isolating a given, important contextual factor such that its causal effect can be established and some of its real-world consequences anticipated. As Moore and Flynn (2010, pg. 418) argued, given that there are undoubtedly many important contextual factors that affect managerial decision making, "researchers should figure out which aspects of context matter and study those aspects in rigorous ways." By enabling controlled

manipulation of the independent variable of interest, the stylized experimental approach allows us to isolate the effect of interdependence on the perception of risk. The control afforded by this method enables us to conclude with confidence that our results are not a product of factors other than the perceptions of interdependence and risk.

Our stylized experiments likely serve as a conservative test of our prediction of greater optimism in situations of greater interdependence. In practice, when considering collaborative agreements, individual partners often focus on the expected benefits; de-emphasize their own challenges and limitations; exaggerate the speed at which they expect to accomplish their tasks; and inflate the forecast of the venture's upside. Indeed, most social factors that one could layer onto our scenarios would likely lead to even greater overoptimism among collaborators. Therefore, our stylized tasks, which focus on risk perceptions, seem to be a conservative first step in understanding managerial judgments and decisions under interdependence, but these complex dynamics certainly warrant future attention.

An additional strength of the experiments presented here is that participants were drawn from a variety of levels of expertise, ranging from inexperienced undergraduate students to experienced executives. Further, the predicted effect of overoptimism in the perception of interdependence was tested with an assortment of related tasks and judgments. Our experiments are cumulative in that each experiment serves to both confirm and build on the results of the preceding experiment. The experiments, as a whole, are a coherent sequence, demonstrating the robustness of the effect through conceptual replication in a variety of participant populations and related tasks.

Experiment 1: Perceiving Co-Innovation Risk

This experiment examined how individuals evaluate interdependent opportunities and tested whether valuations are affected by seeing each partner's separate probability of delivering their respective component vs. seeing only the aggregate probability that all parties deliver their components.

Method. The sample was obtained through the survey company, Clearvoice, which maintains a database of professionals and consumers who have indicated in the past that they are willing to complete surveys for compensation. For the purposes of this research, the pool of potential participants was limited to individuals currently in management positions that were full-time employed, U.S. citizens, and had at least a bachelor's degree. These individuals were invited via email to participate in a "Management Survey." The survey began with two tests to filter out unengaged participants before completing the experimental task.[2]

The final sample consisted of 227 individuals (43.2% female; mean age = 48.9). The participants' were from management roles in many different domains, including accounting, engineering, web development, sales, human resources, and government. They earned $5 for participating in the 8-minute survey.

Participants were asked to make a valuation of an innovation project whose success depends on the development of multiple components. This task was introduced as follows:

> Imagine that you are the CEO of a technology company and are considering a new project for the Department of Education. You could develop a Smart TV — internet-connected television — catered for in-class use by teachers. The Department of

[2] First, participants were tested for consistency. They were asked what was more important for health – nutrition or exercise – using both a binary assessment and also a slider (from 'Nutrition is much more important' to 'Exercise is much more important'). If respondents were inconsistent across these two measures, then their survey was immediately terminated. Second, participants were asked if they would be willing to carefully read instructions because careless participation would ruin the results. If they responded that they were not, then their participation was immediately terminated.

> Education will give you the contract if you can deliver functioning units within 6 months; otherwise, they will renew their contract with their current vendor. If you can deliver the Smart TV by the 6-month deadline, then your company would earn $100 million in revenue. If the Smart TV fails to be delivered within 6 months, then your company would earn $0 in revenue.

Next, they were told that if the contract was pursued, three components would be needed for the product and, to earn the $100 million, all three would need to be successfully developed by the deadline; otherwise, the project was worth $0. The three components had a 30%, 50%, and 70% independent chance of successful development, yielding a joint probability of 10.5% that the project would be successfully completed by the deadline, if pursued.

Experimental manipulation. The manipulation was whether the probability of successful development was presented to the participant by individual component or for the project as a whole. Participants were randomly assigned to one of two experimental conditions. In the separate probabilities condition, participants were shown the independent probability for each component:

> The display has a 70% chance, the processor has a 30% chance, and the backlight has a 50% chance of being successfully developed by the deadline. These probabilities are independent.

The presentation order of the three probabilities was randomized. In the aggregated probabilities condition, participants were instead shown the joint probability that all three components would be successfully delivered by the deadline:

> There is a 10.5% chance that the display, processor, and backlight will all be successfully developed by the deadline.

Otherwise, the conditions were identical.

Measure. Participants assessed the most that their company should be willing to pay to pursue this venture. They were told that company analysts were calculating the total cost, including opportunity costs, for this project and asked to fill in the following blank:

As long as the total cost of this project is less than _____, then the company should undertake this project and go for the contract.

Results. As predicted, there was a significant effect of the presentation of interdependence on the valuation of the project, $t(225) = 4.65$, $p < .001$.[3] The project was valued significantly higher by individuals in the separate probabilities condition (M = \$25.96 million, SD = 18.90, N = 114, SE = 1.78) than individuals in the aggregated probabilities condition (M = \$15.17 million, SD = 15.95, N = 113, SE = 1.49).[4]

Discussion. The result of experiment 1 was that, holding the actual risk of the venture constant, individuals were more risk-tolerant when the chance of the project's success was presented as separate probabilities for each component, as opposed to aggregated into a single joint probability. When the venture was presented with separate probabilities, participants valued the project *as-if* they had risk-seeking preferences. However, in the aggregated-probabilities condition, the mean valuation of the project was similar to that of a risk-neutral valuation. This result – over-optimism when probabilities are presented as separate rather than aggregate – is consistent Bar-Hillel (1973) and provides initial evidence that the presentation of interdependence can have an important effect on judgment and decision-making.

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[3] Two-tailed p-values are reported even for tests of directional predictions.

[4] Fox and Clemen (2005) demonstrated that, under conditions of uncertainty, humans have a tendency to act as if possible outcomes have an equal probability of occurring. In experiment 1, such faulty logic could emerge in a manner similar to the following statement, "The project can either succeed or fail, so the chance of success is about 50-50." Further, Fischhoff and De Bruine (1999) have shown that, in general, 50% is often a default for beliefs about risk. Lastly, if an individual in the separate probabilities condition averaged, instead of multiplied, the three independent probabilities (30%, 50%, 70%) then they would have arrived at a belief that the project had an overall 50% chance of being successful.

In experiment 1, the expected value of the venture is \$50 million, conditional on believing the overall chance of project success is 50%. Can the separate-versus-aggregate experimental result be accounted for by differences across conditions in the propensity to value the project at \$50 million? To answer this question, the model was re-estimated with the omission of participants who had valued the project at \$50 million. There remained a significant effect of experimental condition on the valuation of the project, $t(175) = 3.98$, $p < .001$. The project was still valued significantly higher by individuals in the separate probabilities condition (M = \$15.55 million, SD = 12.16, N = 79), than individuals in the aggregated probabilities condition (M = \$9.49 million, SD = 7.99, N = 98).

In the following experiments we build on Experiment 1 by demonstrating how this phenomenon affects different types of innovation-relevant decisions. Further, to address a potential concern that the online managers from experiment 1 may not have been particularly senior, in experiment 2 we employ a sample from an unambiguously experienced population: high-level executives.

Experiment 2: Number of Co-innovators

This experiment examined how participants' subjective confidence in, and willingness to pay for, an opportunity are impacted by the number of partners on which the venture depends.

Method. The sample was made up of individuals from executive education programs at a highly ranked business school. The executives came from a variety of industries, the most common of which were technology and finance. In preparation for a class session, they were offered the opportunity to complete an online survey that would be discussed the next day. The average age of the executives was approximately 42 and approximately 30% were female.[5] The data collection occurred over four months across five executive education programs. The programs were selected before the start of the experiment with the expectation that they would collectively yield approximately 60 participants per condition. Three executives did not fully complete the survey, yielding a final sample of 141 participants.

In the experimental task, participants were presented with a business opportunity in the form of a multi-party, innovative venture. As in experiment 1, all components needed to be successfully developed in order for the project to payoff for the participant's company.

[5] These demographic summary statistics are to be confirmed.

Specifically, the project would return $1 billion to the participant's company if all of the needed components were successfully developed and $0 if any of the needed components were not successfully developed by the deadline.

Experimental manipulation. The key manipulation was the number of independent parties that needed to develop a component for the venture to be successful, as well as their chances of doing so. Participants were randomly assigned to one of two conditions. In the six-party condition, six components needed to be developed, each with an independent 75% chance of success (an aggregate probability of 17.8%). In the two-party condition, two components needed to be developed, each with an independent 45% chance of success (an aggregate probability of 20.3%). The aggregate probability of success was not presented in either condition. Thus, both conditions involved multiple parties, but the conditions differed as to the number of parties and their independent probabilities of success. The experimental conditions were otherwise identical.

Measures. For this multi-party business venture, the executives answered two questions. First, they reported their subjective confidence by answering the question, "How confident should your company be that, if pursued, this product will be delivered successfully?" on a 1-7 point Likert scale, ranging from 'Not at all confident' to 'Extremely confident.' Second, they stated the most their company should be willing to pay, all costs included, to pursue the project.

There was an additional pair of follow-up questions for all participants. They were presented with a new scenario involving a business opportunity for their company. The opportunity was simply described as a 25% chance at $1 billion for their company. Participants again assessed their subjective confidence in this opportunity as well as the most their company should be willing to pay to pursue it. This enabled a within-subjects comparison between an

interdependent multi-party case (either the 6-party or 2-party) and a pure risky choice (i.e., a one-party case). Note that the expected value across the three cases increases from the six- ($178m) to the two- ($203m) to the one-party case ($250m).

Results. Between-subjects tests of the effect of the experimental condition – 6-party project with 75% chance each *vs.* 2-party project with 45% chance each – were run in SAS. To account for any baseline differences across executive education programs, fixed effects for program were included.

First, we examined the dependent variable of subjective confidence in the venture, which ranged from 1 to 7. Experimental condition had a significant effect on the subjective confidence reported by participants, $t(135) = 2.06$, $p = .04$. Counter to the pattern of expected value, participants reported greater confidence in the project in the six-party condition ($M = 3.58$, $SD = 1.71$, $N = 72$, $SE = 0.20$) than in the two-party condition ($M = 3.06$, $SD = 1.26$, $N = 69$, $SE = 0.15$).

Experimental condition also had a significant effect on participants' valuations of the projects, $t(135) = 3.07$, $p = .004$. Participants in the six-party condition ($M = 210.93$, $SD = 163.33$, $SE = 19.25$) valued the project significantly higher than those in the two-party condition ($M = 138.5$, $SD = 132.18$, $SE = 15.91$).

Next, we proceeded to a within-subject analysis of subjective confidence in the multi-party cases compared to the subjective confidence in the follow-up single-party case (a 25% chance at $1 billion for their company). Participants reported significantly lower subjective confidence in the single party case ($N = 141$, $M = 2.62$, $SD = 1.22$, $SE = 0.10$) than in the multi-party cases, $t(139) = 4.35$, $p < .001$, an effect that did not depend on whether individuals had been in the six- or two-party condition, $F(1, 139) = 1.41$, $p = .24$.

A similar within-subject result was found with project valuations. Participants valued the single-party opportunity (N = 141, M = 99.86, SD = 94.11, SE = 7.93) significantly lower than the multi-party project, $t(139) = 5.27$, < .001, a difference that was larger in the six-party condition than the two-party condition, $F(1, 139) = 5.31$, $p = .02$.

Discussion. The primary result of experiment 2 was that individuals reported higher confidence in, and a higher valuation of, a six-party project in which all six parties had an independent 75% chance of delivering their part, than a two-party project in which both had an independent 45% chance of delivering their part. This is particularly interesting because the expected value of the former opportunity is higher than that of the latter in this case, $178m versus $203m. This result is consistent with the notion that seeing the higher individual probability in the six-party case (75% as opposed to 45%) can cause individuals to anchor on that higher likelihood and be more optimistic about the venture as a whole. It is also consistent with the notion of an underappreciation of the extent to which joint probability is eroded by a greater number of dependencies, causing the case with two conjunctive events to be undervalued relative to the case with six conjunctive events.

Supporting these logics was the within-subjects result: individuals displayed greater conservatism when faced with a pure risky choice for their company of a 25% chance at $1 billion. They reported lower confidence in, and lower valuations of, this single-party opportunity than the multi-party opportunities.[6] The six- vs. two-party between-subjects comparison and the single- vs. multi-party within-subjects comparison paint a similar picture: holding expected value approximately constant (i.e., joint probability multiplied by potential payoff), ventures with more

[6] It should be noted that this within-subjects comparison has a weakness. Given that the experiment's primary purpose was to compare the six-party and two-party cases across conditions, the single-party case always followed the multi-party case. It is possible that individuals were less risk-tolerant after already providing a valuation of a previous opportunity for their company. This, of course, cannot account for the differences between six- and two-party conditions.

parties tend to be viewed more optimistically than ventures with fewer parties. In these cases, greater interdependence appears to yield greater confidence and optimism in risky ventures, *ceteris paribus*.

One question to consider is whether the presence of multiple partners gives rise to potential hopes and expectations that the project will have some salvage value in the event of failure. That is, a greater number of partners may offer, through a greater number of possible recombinations, a greater chance of finding alternative opportunities to pursue. This would be a rational cause of higher willingness to invest in ventures with more partners. Although the instructions in experiments 1 and 2 state that the venture generates no value for their company in the event of failure, it is possible that participants bring in the expectation of partner-induced salvage value. We rule this out as a possible explanation in the design of Experiment 3, in which participants play a one-shot game for real money.

Experiment 3: Adding Co-Innovators

Experiment 3 was designed to accomplish several goals. First, it examined a related, important innovation decision: the number of parties to include in a risky product development. Second, it tested whether interdependence could lead decision makers astray with real money on the line and among a highly math literate population. Finally, it tested whether explicitly reminding participants that the likelihood of conjunctive events is calculated by multiplying probabilities would affect their assessment of interdependent opportunities.

Method. The sample was made up of undergraduate students with a high level of math literacy: students from an Ivey League university where average standard aptitude test scores are

at the 98th percentile among test-takers nationally. According to self-reports, the sample was 52.1% female and 50.3% non-Caucasian; the average age was 20.1 (*SD* = 1.69). Economics, biology, and government were the most represented academic majors in the sample. The students were contacted via email through a participant pool managed by an on-campus research lab and participated through an online survey. In return for 10 minutes of their time, they were guaranteed a minimum of $2 for participation with a chance for a payout as large as $40.

The task involved making a product design decision for an innovative venture. It was clearly stated that the participants' product design choice would determine their probability of receiving the bonus payout, as well as the magnitude of the potential payout.[7]

Experimental manipulations. This experiment was a 2 by 2 between-subjects design. The first experimental manipulation was how the options were framed, either with separate independent probabilities or as a single aggregate probability. Participants were randomly assigned to a framing condition. In the separate condition, participants needed to decide how many partner components to include in the product design. Each single partner component had an independent 75% chance of being successfully developed. For the venture as a whole to be successful, and for the participant to receive their monetary bonus, all components included in the design needed to be successfully developed. The first component was worth a potential payout of $10 and each additional component increased the potential payout by $4. Participants chose a product design with anywhere from one to eight components which then determined their chance at a bonus and its amount. These options correspond to the options in Table 1a.

[7] Following the choice of product design, participants were asked to explain their decision in an open-ended response box. These responses were not used for analysis.

Number of components to include in product design, **each with independent 75% chance** of being successfully developed								
	1	2	3	4	5	6	7	8
Payout	$10	$14	$18	$22	$26	$30	$34	$38

Table 1a: Options available to participants in the separate probability condition in Experiment 3.

Option	1	2	3	4	5	6	7	8
Chance of Success	75.0%	56.2%	42.2%	31.6%	23.7%	17.8%	13.3%	10.0%
Payout	$10	$14	$18	$22	$26	$30	$34	$38

Table 1b: Options available to participants in the aggregate probability condition in Experiment 3.

In the aggregate condition, the exact same options were offered but were presented simply as a risky choice. Each option was presented with an overall probability of success and a potential payout (as shown in Table 1b). Participants selected one of eight product design options, which then determined their chance at a bonus and its amount. The aggregate condition served as a useful benchmark because it elicited the risk-preferences of individuals when interdependence was eliminated from the problem framing.

Note that the expected value maximizing choice in both conditions is option 2.

The second experimental manipulation was the timing of a question about how to compute joint probabilities, which occurred either before or after the product design choice. Participants were shown the following question:

> Three coins will be flipped. Each has an independent 50% chance of being heads. What is the probability that all three come up heads?

This wording mirrored the wording in the interdependence condition describing the independent 75% chance that each component would be successfully developed. Participants were asked,

"What is the logic you would use to come up with an answer?" Among four multiple choice options, one was "Multiply the probabilities," which was the correct answer. The other options were averaging, adding, and subtracting probabilities. This question and manipulation served two purposes. First, the question measured whether individuals could correctly report the process for computing joint probabilities. Second, the experimental manipulation enabled a test of whether raising attention to the logic of joint probability would affect product design decisions with interdependent parts: half of participants answered this question before the product design decision and half answered it after.

Results. First, we examined the participants' responses to the coin question. In general, participants had a good understanding of the logic needed to solve the coin question: 95% of participants correctly selected that one must multiply the independent probabilities to compute joint probability of flipping the coin three times.

To analyze the product design decisions, a between-subjects general linear model was estimated with the following independent variables: framing condition (separate, aggregate), coin question timing (before product design choice, after product design choice), and an interaction term.

Overall, there was a significant difference in product design choices between the separate and aggregate conditions, $t(161) = 3.33$, $p < .001$. Recall that higher numbered options involved lower probabilities of success, but greater potential payoff. Participants in the separate condition ($N = 85$, $M = 3.0$, $SD = 1.80$, $SE = 0.14$) demonstrated a preference for higher risk and higher potential reward than individuals in the aggregate condition ($N = 80$, $M = 2.2$, $SD = 1.28$, $SE = 0.20$). In the aggregate condition, the median option chosen was the expected value maximizing option, option two – a 56.2% chance at $14. In the separate condition, the median option chosen was a design with three components – a 42.2% chance at $18 – which involves greater risk than

the expected value maximizing option. Figure 1 shows the distribution of design choices across the two conditions.

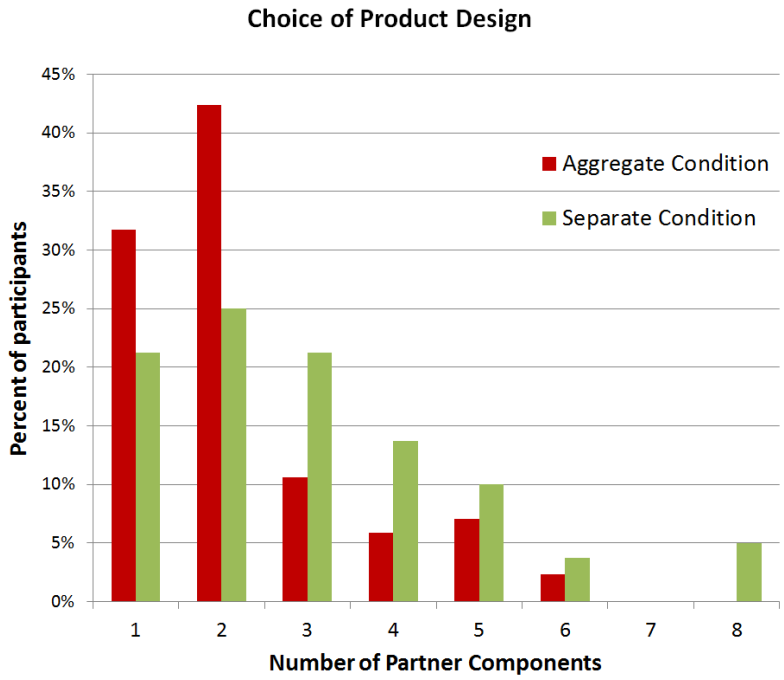

Figure 1: The distribution of product design choices across conditions in Experiment 3.

Interestingly, the effect of framing condition (separate vs. aggregate) was not moderated by whether the coin question was answered before or after the product design decision. That is, there was no significant interaction between framing condition and the coin question timing, $F(1, 161) = 0.00$, $p = .96$. Additionally, there was no main effect of the coin question timing on design decisions, $t(161) = 0.18$, $p = .86$.

Thus, it made no difference whether the coin question prompting participants to consider how to compute joint probabilities was answered before or after the product design. The evidence is not consistent with the notion that individuals simply do not understand the need to multiply probabilities when faced with interdependence. Rather, participants well-understood how to compute joint probabilities and their awareness of how to compute joint probabilities did not affect their design decisions in either framing condition.

Discussion. The key result from Experiment 3 was that individuals opted for greater risk (and lower expected value) when the problem was framed with interdependence, than when it was framed as a pure risky choice. Note that this effect is manifest in a rightward shift in the overall distribution of choices, rather than in a completely new distribution, such as bi-modal (see Figure 1).

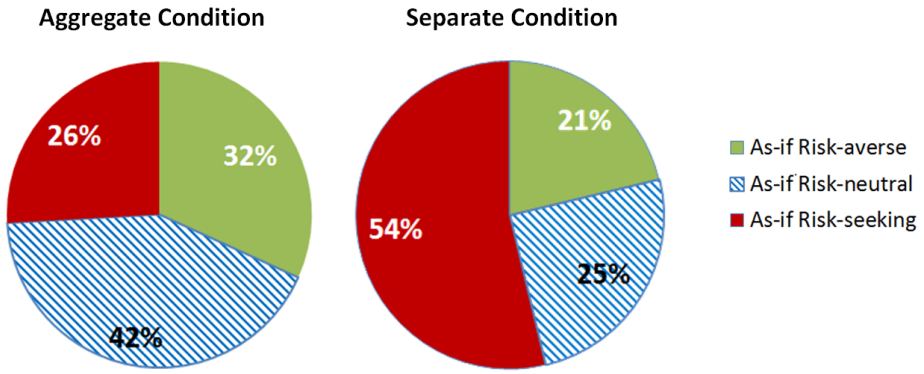

Figure 2: Percent of choices in each condition that are consistent with risk-aversion, risk-neutrality, and risk-seeking in Experiment 3.

The separate presentation of interdependence appears to nudge individuals to be more risk-seeking in their behavior. To consider the magnitude of this effect, we assess participants' choices relative to the risk-neutral expected value maximizing choice (option 2: two partners) across the separate and aggregate conditions. As illustrated in Figure 2, in the aggregate condition the majority of participants (74%) opted for a product design that was consistent with risk-neutrality or risk-aversion. In contrast, in the separate condition we see a dramatic swing, as the majority (54%) chose product designs that were consistent with risk-seeking. Random assignment assures that risk preferences cannot account for the differences across conditions, but the stark differences in observed behavior are *as-if* participants did have different risk preferences across conditions.

These results have a clear implication. One should expect managers to make riskier choices in the context of multi-party innovative ventures when the aggregate chance of success for the project is not explicitly presented to the decision-maker.

Experiment 4: Task structure and opportunity valuation

The purpose of this experiment was to examine the effect of task structure on the perception of risk in interdependent ventures. When considering a multi-party venture where each party must develop a critical part to an integrated product, the manager of one of these parties must consider the chances of success for each critical partner to form an opinion of the value of the opportunity for his or her company. We examined two ways that this process could be structured to improve judgment and valuations. First, an individual can be required to explicitly estimate the conjunctive probability for the venture as whole before making their valuation of the opportunity. This may cause the individual to think more deliberatively about the venture and dwell on the aggregate chance of success which may deflate the optimism observed in the previous studies. Second, the estimation of aggregate chance of venture success and the valuation of the opportunity can be done by two different individuals. One person can observe the separate probabilities and estimate the conjunctive probability; a second individual can observe the first person's estimate of the aggregate chance of success and then place a valuation on the opportunity. Dividing the estimation and valuation across people in this manner may achieve two things: (i) the risk assessor must explicitly consider aggregate risk for the overall venture, and (ii) the ultimate evaluator is insulated from observing the higher chances of success for each individual partner, thereby avoiding any potential spillover of optimism in the

form of intuitive confidence. These two possible structures were compared to the cases examined in previous studies: only observing the separate independent probabilities of success for each needed part, or only observing the aggregate probability of overall venture success.

Method. The sample consisted of 898 managers (41.2% female; mean age = 47.3) reached via the Clearvoice survey company as outlined in Experiment 1. These were professionals who had previously agreed to be contacted for survey research. The participants were in managerial positions, between the ages of 25 and 60, U.S. citizens, and had at least a Bachelor's degree. They received $5 in exchange for their participation in an 8-minute survey.

They played the role of a Vice President at a technology company. Their company had an opportunity to pursue a new venture, which would be the development of a product with integrated components. For the overall venture to be successful, six different components would still need to be developed by an upcoming deadline (five components by partner companies and one by their company). If the venture were to be pursued, then there would be two possible financial outcomes for their company. If all six components are successfully developed, then the overall venture would be successful and their company would earn $100m. If any of the six components failed to be developed, then the overall venture would fail, and their company would earn $0. The manner in which the chance of venture success was presented depended on experimental condition. Participants then proceeded to place a valuation on the potential venture. Participants were informed that company analysts were calculating the total cost (including opportunity costs) for this potential venture and that it would be up to the participant to decide whether the company should do the venture. They then stated their valuation of the project by filling the blank in the following statement, "As long as the total cost of this venture for my company will be less than _____, then my company should do the venture."

Experimental manipulation. This experiment had four conditions (a 4x1 between-subjects study design). In the *aggregate* condition, participants were simply informed that, if the venture was pursued, their best estimate of the probability that all six parties would be able develop their part was be 18%. The separate probabilities for each partner's independent component were not mentioned in this condition.

In the *separate* condition, participants were informed that, if the venture was pursued, each of the six involved parties would have an independent 75% chance of successfully completing their needed component.

In the *within-estimation* condition, risk was presented in the same manner as in the separate condition: participants were informed that, if the venture was pursued, each of the six involved parties would have an independent 75% chance of successfully completing their needed component. However, they were additionally asked to submit their best estimate of the probability that all six parties would be able to develop their part.

In the *between-estimation* condition, the (i) assessment of the risk and (ii) the ultimate valuation of the opportunity were done by two different participants. Therefore, each observation in this condition was actually a pair of participants. The first participant observed and estimated risk exactly as was done in the within-estimation condition. These participants were informed that, if the venture was pursued, each of the six involved parties would have an independent 75% chance of successfully completing their needed component. They then made their best estimate of the probability that all six parties would be able to develop their part. Their estimate was then passed on to a second participant who was simply shown their partner's estimate of the probability of overall venture success. These second individuals were simply informed that, if the venture was pursued, their best estimate of the probability that all six parties would be able develop their part was what their partner had estimated.

Three predictions were made. First, as in previous experiments, we predicted that valuations of the potential venture would be higher in the separate condition than in the aggregate condition. Second, we predicted that valuations in the within-estimation condition would be lower than those in the separate condition. Third, we predicted that valuations in the between-estimation condition would be lower than those in the separate condition.

Results. Note that in all conditions, a risk-neutral valuation of the opportunity would be $17.8m. Testing our first prediction, we found that valuations were significantly higher in the separate condition ($N = 174$, $M = 24.04$, $SD = 22.33$, $SE = 1.69$) than in the aggregate condition ($N = 190$, $M = 15.23$, $SD = 13.95$, $SE = 1.01$), $t(362) = 4.55$, $p < .001$.

We then tested whether explicitly estimating the chance of overall venture success mitigated the inflated valuations observed in the separate condition. Valuations in the within-estimation condition ($N = 180$, $M = 20.69$, $SD = 20.33$, $SE = 1.52$) were only slightly, and not significantly, lower than those in the separate condition, $t(352) = 1.48$, $p = .14$. However, dividing the aggregate risk estimation and opportunity valuation tasks across two different individuals significantly reduced the bias. Valuations in the between-estimation condition ($N =$ 177 pairs, $M = 17.72$, $SD = 17.69$, $SE = 1.33$) were significantly lower than those in the separate condition, $t(349) = 2.94$, $p = .004$.

In fact, valuations in the between-estimation condition were not significantly different from those in the aggregate condition, $t(365) = 1.50$, $p = .14$. On the other hand, valuations in the within-estimation condition were significantly higher than those in the aggregate condition, $t(368) = 3.02$, $p = .003$.

Discussion. Once again, we found that, when an interdependent risky venture is presented in terms of the chances of successful development for its individual parts, individuals

are more optimistic about the opportunity than when the aggregate chance of venture success is presented. However, in this study we also explored how task structure affects this overoptimism. First, we found that requiring individuals to explicitly estimate the chance of overall venture success did not affect subsequent valuations of the opportunity. However, a different structural change did significantly lower valuations: dividing risk assessment and opportunity valuation across two individuals. Having one individual estimate the aggregate chance of venture success and then having a second individual (given the estimate from the first individual) make the valuation of the opportunity significantly improved valuations. This structure notably insulates the individual responsible for placing a value on the opportunity from observing the high chances of success for any single partner (which are always higher than the aggregate chance of venture success).

General Discussion

This study demonstrates that individuals are subjectively more optimistic about opportunities that feature more interdependence. We show that this bias arises from the presentation of interdependence as well as from the extent of interdependence. In Experiments 1, 3, and 4, we find that individuals place higher value on projects when they are presented with the probabilities of success for critical independent components than when presented with the aggregate probability of success for the venture as a whole. In Experiments 2, 3, and 4, we find that increasing the number of participating partners in a venture, increases individuals' confidence in, and willingness-to-pay for, the venture.

Any approach to managing interdependence is built on the way in which interdependence is perceived. Our findings in this paper highlight how dependence on critical partners impacts

assessment and valuation of opportunities and prioritization of interventions. While no single experiment presented here provides an exhaustive examination of the perception of interdependence, collectively, the six stylized experiments offer compelling support for the proposition that opportunities characterized by greater interdependence leave participating individuals subjectively more confident and optimistic than equivalent situations with less interdependence. We approached this phenomenon using a variety of decisions (valuation, design, and intervention) and a variety of participant types (business executives, undergraduates, and an online panel of managers), and robust findings across the six experiments increase our confidence in the presence of this causal relationship.

Our experiments are highly stylized, and will clearly benefit from complementary research that explores the rich and nuanced settings in which the decisions of interest are reached in real-world settings. We note, however, that the very simplicity of the experimental settings positions them as conservative tests. We eliminate real-world considerations such as the politics of spreading blame for failure; groupthink and the contagion of optimism among enthusiastic partners; the potential of overoptimism regarding both upside (e.g., more partners increase possibility of finding additional opportunities in future) and downside (e.g., more partners increase possibility of finding fallback alternatives in the case of initial failure). Indeed, finding strong results of overoptimism in the absence of these possibilities begs the question of how much more over-optimistic managers can become in the presence of these factors.

We believe this study is a useful first step in developing an understanding of how interdependent ventures are perceived, and also a contribution to the broader literature on interdependence. Here we explore interdependence as a generic construct, and expect that rich insight can be generated by further examining its multiple facets, for example difference among the impact of pooled, sequential and reciprocal relationships among partners (i.e., Thompson

1967). Moreover, we expect that interactions between number of partners and other factors – differences in identity of partners and in temporal treatments/factors such as historic reputations, longevity of ventures, the possibility of future interactions – will all give rise to interesting behavioral shifts regarding the decisions of interest.

Even as an early step, our study raises a number of important implications. We are witnessing a near-universal trend for organizations across the economic spectrum – from corporations, to non-profits, to governments – to pursue innovation and growth through greater collaboration. In this light, the partnership-rooted bias towards over optimism in the face of interdependence identified in this study suggests that the very nature of these collaborations makes decision makers more susceptible to unintentional risk taking and, as a result, to misplaced priorities in their investments and commitments.

Absent procedural adjustments that explicitly and overtly guide managers to confront the holistic risks that underlie their initiatives – that is, mechanisms that shift from the separate to the aggregate conditions in our experiments – we can expect decision makers and their organizations to suffer from over-reliance on partners; over investment in collaborative initiatives; and the under-management of interdependence. To be clear, the implication is not to avoid interdependent opportunities; rather, it is to make sure that choices about interdependent opportunities are approached with the fullest possible recognition of their implications.

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