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Interdependence, Perception, and Investment Choices: An Experimental Approach to Decision Making in Innovation Ecosystems

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Abstract. We explore how decision makers perceive and assess the level of risk in interdependent settings. In a series of five experiments, we examine how individuals set expectations for their own project investments when their success is contingent on the success of multiple, independent partners. We find that individuals are subjectively more confident and optimistic in an interdependent venture when its chances of success are presented as separate probabilities for each component and that this optimism is exacerbated by a greater number of critical partners, leading to (1) the inflation of project valuations, (2) the addition of excessive partners to a project, and (3) overinvestment of effort in the development of one's own component within an interdependent venture. We examine these dynamics in settings of risky choice (with exogenously given probabilities) and in an economic coordination game (with the ambiguity of agency and strategic risk). 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 should approach and assess their innovation choices in ecosystem settings.

Keywords: innovation • ecosystem • judgment and decision making • interdependence

Introduction

Confronted with mounting 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 2009, Gulati et al. 2012). 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 1993; Iansiti and Levien 2004; Adner and Kapoor 2010; Adner 2013, 2017).

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 individual partners. 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?

In this article, we show that managerial obstacles arise in interdependent settings not only from the challenge of recognizing all of the critical partners on which one's value proposition depends (which has been the focus of previous literature), but also from a systematic bias toward optimism in the interdependent venture as a whole. We draw a distinction between awareness of interdependence and perception of interdependence. Awareness of interdependence is about knowing who one's critical partners are. In contrast, perception of interdependence, although conditional on awareness, is about integrating the knowledge of interdependence into an assessment of the overall opportunity. We show that the perception of interdependence gives rise to this systematic bias even in contexts with perfect awareness.

To illustrate how dependence on multiple partners can cause problems for the subjectivity of risk perception, consider the following two meetings. In meeting A, five partners are discussing the attractiveness of a potential joint initiative, in which each one's contribution is critical for overall success. All five have aligned interests and commit to assigning their best resources to their respective component, and each component is completely independent of the others. Further, every one of them has high expectations for completing the task: each of the five assesses that it has an 85% chance of successfully developing its particular component by the deadline.

Meeting B is identical: five partners are discussing the attractiveness of a potential joint initiative and similarly express a willingness to commit their best effort to their

respective tasks. 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%.

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 ventures have identical chances of achieving overall success: $0.85^5 = 0.44$. However, we have found that individuals typically display greater optimism about the joint venture in meeting A. This tendency matters because shifts in optimism translate to shifts in risk taking, commitment, and investment.

In both meetings in the example, participants have perfect awareness of their interdependence. The key difference is in the presentation of the chances of success: either separately for each needed component or in aggregate for the venture as a whole. This difference in the way the chances are presented impacts what we refer to as the "perception" of interdependence. We find that when interdependent opportunities are presented in terms of their separate components, they are perceived more favorably, giving rise to a systematic behavioral bias that leads to naive choices and excessive risk taking.

In this paper, we examine the intersection between psychological biases and the management of innovation. The meeting example is an example of conjunctive interdependence, in which a focal actor's success is dependent not only on its own ability to execute the task, but on the successful execution of other tasks by other actors. A positive predisposition toward conjunctive events (relative to their single-event equivalents) has long been noted in classic psychology literature. Foremost, Bar-Hillel (1973) found that individuals exhibited a preference for conjunctive gambles over one-shot gambles that were formally identical.[1] This result was attributed to a human tendency to overestimate the likelihood of conjunctive events. Although we do not contest the overestimation mechanism posited by that work, we show that this result can occur even in the absence of any calculative burden. Thus, beyond applying a finding from the field of psychology to the field of management, we shed light on a new mechanism for an important finding.[2]

Conjunctive interdependence is characteristic of ecosystem settings (Adner and Kapoor 2010, Adner 2017). Although the strong-form all-or-nothing framing of the meeting example is often softened in practice by the opportunity for innovators to retain some residual value in the event that at least one partner fails to deliver its respective part, the basic challenge of setting expectations when the achievement of significant value is contingent on successful execution by multiple parties is a defining attribute of innovating in ecosystems. For example, in 2000, Nokia forecast that by 2002 more than 300 million handsets would be connected to the mobile internet to take advantage of mobile services actively in development, such as real-time videos, mobile payments, and workforce productivity applications. This expectation informed its public commitments, strategic priorities, and the urgency of its 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 three million, 100 times fewer than forecast. Delays in the availability of coinnovations, 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 coinnovations were successfully developed, 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). Whenever a focal actor depends on other parties to achieve its goals, there is an inherent element of conjunctive interdependence, which, in turn, gives rise to the question of how this interdependence will be perceived.

In this paper, we examine how different presentations of interdependence affect how attractive multiparty opportunities are perceived to be. In so doing, we introduce a behavioral decision-making lens to the question of managing interdependence. Across five experiments, we examine how the presentation of interdependence (showing the probabilities for individual components rather than the overall project) and the extent of interdependence (increasing the number of critical partners) affect judgment and behavior. We find that individuals are subjectively more confident and optimistic in an interdependent venture when its chances of success are presented as separate probabilities for each component and that this optimism is exacerbated by a greater number of critical partners, leading to (1) the inflation of project valuations, (2) the addition of excessive partners to a project, and (3) overinvestment of effort in the development of one's own component within an interdependent venture. We conduct our study with a wide range of participant samples, ranging from undergraduates to senior executives. In some cases, we observe that the shift from aggregate to separate presentations of interdependence can shift the choices of decision makers from acting as if they were risk neutral to acting as if they were risk seeking. Collectively, our finding of a systematic bias toward overoptimism when dependent on partners—even when only considering risk perceptions—has clear implications for innovation management and organization design.

Contribution

We make four distinct contributions to our understanding of the psychology of conjunctive value creation

and its consequences for innovation management in organizations.

First (and perhaps least interestingly), where Bar-Hillel's (1973) classic experiments and more recent follow-up work have used samples of high school and college students, we use a variety of samples, including senior corporate executives.

Second, and more importantly, we provide evidence of a contributing mechanism that was unidentified in past work on conjunctive events: exposure to the likelihood of the subevents makes one look more favorably on the aggregate chance of success *even when* the aggregate chance is known. Identifying this additional mechanism is important because it implies that even when decision makers are highly motivated—for example, making explicit calculations to estimate the aggregate chance of success—conjunctive value creation is likely to generate additional optimism regarding the overall project. We show that, because individuals dwell on the higher likelihoods of the subevents while determining the aggregate, the very exposure to those higher likelihoods gives rise to an intuitive confidence that generates optimism in the overall venture (i.e., Slovic et al. 2002 and Simmons and Nelson 2006).

Third, we demonstrate two novel behavioral manifestations of this psychological bias that are critical for management. Individuals opt to increase their dependence on partners—even increasing their risk while decreasing their expected return—when presented with the separate chances of success for each partner relative to when they are presented with the aggregate chance of project success. Also, individuals overinvest effort in the development of their part within an interdependent venture, failing to sufficiently account for the likelihood of a holdup with at least one partner, thereby hurting their expected return.

Finally, we show that the overoptimism with conjunctive events emerges even when decision makers face uncertain strategic interactions with other individuals. We find that our effects hold beyond settings in which participants are presented with exogenously determined probabilities. In so doing, this paper is the first, to our knowledge, to connect the psychology literature on conjunctive events to the experimental economics literature on coordination games. Altogether, we demonstrate the key effect with both nature-based risk and agent-based uncertainty, highlighting how the underlying phenomenon explored in this paper has relevance for a wide variety of managerial decisions that are critical to organizational success.

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 machine tool industry to Hughes's (1983) study of the development of the electrical power system to the examination by Bresnahan et al. (1996) of the role of coinvention 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 1993; Iansiti and Levien 2004; Adner 2006, 2013; Adner and Kapoor 2010, 2016; and Kapoor and Furr 2015) examines firm strategies in designing and managing such interdependent systems as do game-theoretic approaches to competing in ecosystem contexts (e.g., Zhu and Liu 2014 and Mantovani and Ruiz-Aliseda 2016). Throughout this stream, however, the consistent underlying assumption is that firms and managers either have or work toward an awareness of interdependence. 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, Lawrence and Lorsch 1967, and Thompson 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 (Pfeffer and Salancik 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 underlying assumption is that awareness of interdependence implies objectivity about interdependence. The question of perceptual biases in incorporating interdependence into design and decision making has been largely absent from these discussions. In one notable exception, managers were shown to underappreciate the communication and coordination inefficiencies caused by scaling up team size for a project, causing the managers to make biased forecasts of the total labor time needed for large-team projects (Staats et al. 2012). Although there is increasing focus on the role of perception as regards task division and task allocation (e.g., Raveendran et al. 2015), the role of perception regarding how managers aggregate divided tasks in their decision-making process has received little attention in the organizations literature.

The way managers perceive the aggregation of interdependent tasks matters because the very choice of engaging in interdependent projects gives rise to

compounding risk. Introducing 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 a partner. Impartially and rationally assessing conjunctive risk is, thus, a foundational challenge to managing modern innovation. By explicating the potential for subjectivity in the perception of interdependence on partners, our study contributes to the literature's goal of more productive assessment and management of interdependence.

In Experiment 1, we study the decision to green light a conjunctive project and whether it depends on how the risks involved are presented: either separately for each needed part or in aggregate for the project as a whole. Participants reported a higher willingness to pay (WTP) for the opportunity when presented with the separate probabilities than when presented with the aggregate probability. The average valuations with aggregated probabilities were *as if* the individuals had risk-neutral preferences, whereas the average valuations with separate probabilities were *as if* the individuals had risk-seeking preferences.

In Experiment 2, we test whether overoptimism in conjunctive events can be caused by intuitive confidence, independent of any misestimation of the aggregate probability. We compare a case in which only the aggregate chance of success is presented with a case in which the separate chances of success for each part are presented first, followed by the aggregate probability. We find greater optimism in the venture in the latter case. Knowing and dwelling on the subevents with their higher individual likelihoods generates overoptimism relative to only ever having seen the aggregate chance of success.

In Experiment 3, 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 coinnovations with an independent 45% chance of success for each, and the second depended on six coinnovations 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 4, in a setting with real financial rewards, 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 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, and 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 (i.e., more dependence on partners) than when the options are presented with aggregate probabilities visible. This occurred even when participants were primed to consider independent probabilities with the analog of a coin toss and reminded to multiply probabilities when faced with a conjunctive event.

In Experiment 5, we study behavior in an interactive multiplayer setting: a weak-link coordination game. We extend our findings to a case in which the risk faced by the individual (1) arises from strategic interactions with other participants rather than being presented as an exogenous and known probability and (2) is the product of agency risk from strategic interactions rather than simple execution risk. Here we had participants self-report their own expectations regarding the choices that other players would make. When we showed participants the aggregate implications of their own beliefs about what other players would tend to do, participants were more conservative in their project prioritization. They also earned more money.

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 and case studies (Adner 2006, 2013), the limitations on generalizability from stylized experiments certainly apply.

However, there is also considerable value in isolating specific contextual factors such that their causal effects can be established and some of their real-world consequences anticipated. As Moore and Flynn (2008, p. 418) argue, 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 the presentation of interdependence on critical managerial choices.

Note that our stylized experiments 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.

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 Coinnovation Risk

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

Methods

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 purpose 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.[3]

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 eight-minute survey.

Procedure and Design. 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 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. If any of the three failed to be developed by the deadline, then the project was worth $0. To ensure that our sample of participants understood the conjunctive nature of the value proposition, immediately after reading the instructions, we asked, "How much revenue ($) will the project make for your company if any one of the needed components is not successfully developed by the six-month deadline?" This served as a comprehension check, and a correct response was a prerequisite for continued participation: any participant who responded incorrectly (i.e., a number other than $0) had the survey immediately terminated.

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. To help ensure that participants did not infer a false correlation among components, we explicitly stated that the probabilities were independent and presented the components as distinct, separate technologies.

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.

Hence, the risks across the two cases were formally equivalent (70% × 30% × 50% = 10.5%), and the conditions were otherwise identical. The measurement of the dependent variable occurred as follows. Participants assessed the most that their company should be willing to pay to pursue the 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[4]

Valuation of Opportunity. There was a significant effect of the presentation of interdependence on the valuation of the project, $t(225) = 4.65$, $p < 0.001$. As predicted, the project was valued significantly higher by individuals in the separate probabilities condition (mean (M) = \$25.96 million, standard deviation (SD) = 18.90, n = 114, standard error (SE) = 1.78) than individuals in the aggregated probabilities condition (M = \$15.17 million, SD = 15.95, n = 113, SE = 1.49).

Discussion of Experiment 1

Holding the actual risk of the venture constant, individuals viewed the project more favorably 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.

There are several questions that should arise at this point. First, it is possible that participants did not know how to compute the likelihood of conjunctive events (multiplying the probability of the subevents). Second, the online panel of managers who participated in Experiment 1 may not have been particularly accomplished or senior. Third, participants may have lacked motivation given the absence of incentives. Finally, results derived from settings in which participants are presented with exogenous probabilities may not translate to settings in which likelihoods are more ambiguous and in which agency and strategic interactions play a role in determining outcomes. The following four experiments will address each of these concerns in addition to extending and building on the finding. In Experiment 2, we isolate a contributing mechanism that occurs over and above any misestimation of the aggregate chance of success. In Experiment 3, we replicate the pattern of results using a sample of executives. In the final two experiments, we find the same pattern of behavior with performance incentives in settings characterized by purely probabilistic risk (Experiment 4) and agent-based risk (Experiment 5).

Experiment 2: Intuitive Confidence from Separate Probabilities

To determine the chance that a conjunctive event occurs when the required subevents are independent, one must multiply the likelihoods of the subevents. Bar-Hillel's (1973) classic paper posits that people intuitively overestimate the likelihood of conjunctive events because they underappreciate the extent to which multiplying probabilities deteriorates the aggregate likelihood. Literature reviews and follow-up experimental work on the psychology surrounding conjunctive events have similarly attributed the effect to a mental miscalculation (e.g., Tversky and Kahneman 1974, Brockner et al. 2002, Bazerman and Moore 2012, Nilsson et al. 2013, and Khemlani et al. 2015). This explanation attributes the bias in risk assessment to the subject being a "lazy statistician"—the implication is that, if only the subject had access to a calculator, the bias would go away. Put another way, this logic implies that, with greater effort, deliberation, and calculation on the part of the individual, the effect should disappear.

Although people may indeed tend to intuitively misestimate conjunctive likelihoods, we show the presence of a different and independent cause for this bias. This second cause, intuitive confidence, exists even in the absence of any calculative burden and helps explain why the observed bias toward optimism with conjunctive events is so pervasive.

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 subevents in question will always be higher than the likelihood of the conjunctive event. Therefore, one will be more confident in the chance of success for any single subevent than in the chance of success for the conjunctive event. This greater confidence in the subevents may then spill over into confidence in the aggregate chance of success, leaving one more optimistic about the aggregate than if the likelihoods of the subevents were unknown. In other words, knowing that the likelihood of a given conjunctive event is the product of subevents that are all individually quite likely may make one feel better about the likelihood of that conjunctive event.

Slovic and colleagues have studied how individuals use intuitive feelings, often nonconsciously, as information to guide decision making under risk and uncertainty (Slovic et al. 2002, Slovic and Peters 2006). This research emphasizes the difference between objective risk (the formal reality) and subjective risk (the experience of the individual). Numerous studies have shown that a different framing of formally equivalent risk—particularly one that generates a different intuitive perception—can have a large effect on behavior (see Rottenstreich and Hsee 2001 and Loewenstein et al. 2001). Even motivated and careful decision makers are known to start with an intuitive reaction and then integrate additional information as it arrives and as they further deliberate (Simmons and Nelson 2006). In this manner, our initial intuitive reactions shade our deliberated conclusions. One can observe an objective probability but feel more or less subjectively optimistic

about it depending on contextual factors that affected one's initial reactions. In the context of conjunctive events, because the subevents will always have a higher probability than the conjunctive event, forming an optimistic intuitive impression of the subevents may yield a carryover effect of optimism even when subsequently observing the exact likelihood of the conjunctive event.

The following experiment is the first, to our knowledge, to show that overoptimism with separate component probabilities can emerge even after the true aggregate probability is also presented. In this manner, we isolate how knowing and having dwelt on the fact that the aggregate is derived from subevents that are individually more probable can generate optimism regarding the aggregate chance of success.

Methods

Given the lower costs of a sample acquired through Mechanical Turk (mTurk), we requested from mTurk a sample of 1,000 individuals that had attained at least a bachelor's degree. One thousand three individuals entered the survey, and a series of predetermined attention and comprehension checks were used to identify individuals that were answering carelessly, such that they could be removed from the survey before completing our experimental task.[5] The final sample was 885 participants (53% female, $M_{age} = 38.8$, $SD = 14.23$, 97% completed a bachelor's degree) and received $1 in exchange for completing the five-minute survey. No analyses were conducted until data collection was completed.

Procedure and Design. Participants were told that their company has the opportunity to invest in the development of a new product. If the innovation process is successful, then their company would earn $100,000 in revenue. If their company invests and the innovation process fails, then their company would earn $0 in revenue. The overall chance of success for the venture was 18%, but this risk was presented in different ways depending on experimental condition, which we return to momentarily.

Participants assessed the attractiveness of this opportunity in two stages. In *stage 1*, participants reported their sense of confidence in the opportunity by answering the following question: "How confident are you that, if pursued, this venture as a whole will be successful?" They answered this question on a seven-point Likert scale ("not at all confident" to "extremely confident"). In *stage 2*, participants placed a valuation on the opportunity by responding to the following:

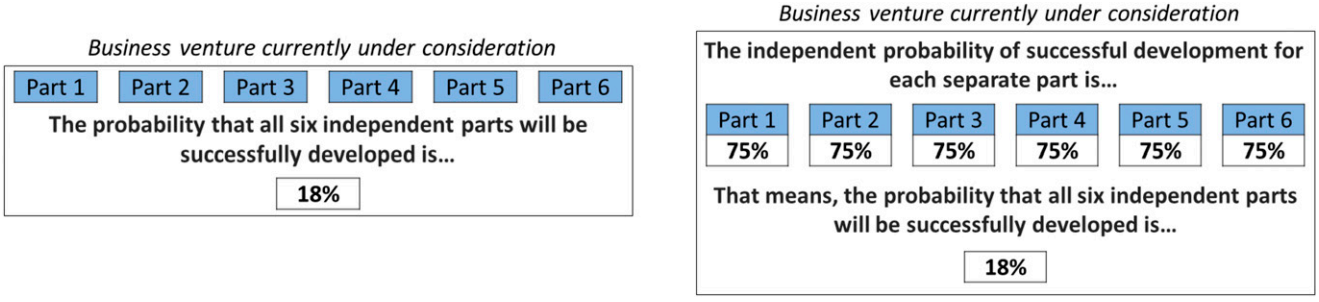
> Objective analysts are currently determining the costs for your company, including opportunity costs, of pursuing this venture. Please place a valuation on this potential business venture by filling in the following blank: "As long as the cost for my company will be less than _____, then my company should do this project."

Participants were randomly assigned to one of two conditions. In the *aggregate-then-aggregate condition*, in both stages 1 and 2, the opportunity was presented only in terms of the aggregate probability: 18% (see Figure 1, left).

In the *separate-then-aggregate condition*, in stage 1, the opportunity was presented only in terms of the independent probabilities of successful development for each separate part: an independent 75% chance for each. Then, in stage 2, participants were additionally presented with the aggregate chance of project success, 18% (see Figure 1, right). This case is representative of one in which a manager first considers each of the needed independent parts for a project. Once each part and its individual chance of development has been considered, the manager then learns or computes what these separate risks mean for the aggregate chance of project success. The question then is whether first cognitively processing the separate chances of development has a spillover effect in how one feels about the aggregate chance of venture success.

Figure 1 shows the visual depiction of the parts that needed to be developed and the chances of overall

Figure 1. (Color online) Images Presented to Participants at Stage 2 in the Aggregate-Then-Aggregate Condition (Left) and Separate-Then-Aggregate Condition (Right) in Experiment 2



success seen in stage 2 of the experiment in each of the experimental conditions.

Results

Subjective Confidence. At stage 1, self-reported subjective confidence was significantly higher for individuals in the separate-then-aggregate condition (M = 4.41, SD = 1.45, n = 435, SE = 0.07) than for individuals in the aggregate-only condition (M = 2.17, SD = 0.96, n = 450, SE = 0.43), $t(883) = 27.14$, $p < 0.001$.

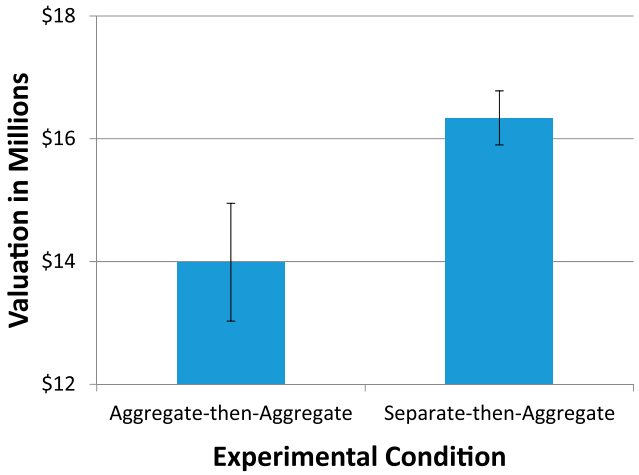
Valuation of Opportunity. At stage 2—now with the aggregate chance of success explicitly stated to participants in both conditions—there was a significant effect of the presentation of interdependence on the valuation of the project (see Figure 2). As predicted, the project was valued significantly higher by individuals in the separate-then-aggregate condition (M = \$16.34 million, SD = 9.17, n = 435, SE = 0.44) than by individuals in the aggregate-then-aggregate condition (M = \$13.99 million, SD = 9.15, n = 450, SE = 0.43), $t(883) = 3.82$, $p < 0.001$ (see Figure 2).

Discussion of Experiment 2

When individuals were presented with separate component chances of success in advance of and in addition to the aggregate chance of project success, individuals placed higher valuations on the project than when they were only presented with the aggregate chance of project success. This experiment isolated a mechanism that operates beyond the misestimation of conjunctive likelihoods: observing and dwelling on the separate component probabilities that are, mathematically, always higher than the aggregate chance of success leave individuals more subjectively confident in the aggregate probability. This result implies that when both separate probabilities and the aggregate probability are visible to the decision maker, this spillover confidence is likely increasing in the amount of attention given to the separate probabilities relative to the aggregate chance of venture success. This mechanism was underappreciated in past work (Bar-Hillel 1973), which instead focused on a misestimation of the actual aggregate probability. Of course, when only separate probabilities are presented in practice, both mechanisms are likely to be in effect. Therefore, for projects with conjunctive value creation without an aggregate chance of success explicitly known, overoptimism is especially likely to emerge as each of the two mechanisms nudge the manager toward overvaluation.

One important implication of our result is that, in a high-stakes, real-world setting, greater effort and analysis—for example, deliberative calculation of the aggregate chance of venture success—may not be sufficient to eliminate excessive optimism in conjunctive projects. We found that mere exposure to the (comparably favorable) likelihoods of the subevents, which is necessary for determining the aggregate chance, makes one look at the project as a whole more favorably; this result means that careful calculation alone may not be enough to offset interdependence-based judgment bias.

Figure 2. Participants' Valuations of the Project Across Experimental Conditions in Experiment 2



Experiment 3: Number of Partners with Executives

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. The sample was senior business executives.

Experiments 1 and 2 demonstrated the effect while referring to each needed subevent as "components" or "parts." In Experiments 3–5, we refer to each needed subevent as being associated with a "partner." We find consistent effects across the experiments, which increases our confidence that the effect is not contingent on a particular label.

Methods

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 asked 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. 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.

Procedure and Design. In the experimental task, participants were presented with a business opportunity in the form of a multiparty, innovative venture. As in the previous experiments, all components needed to be successfully developed for the project to pay off for the participant's company. 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.

The key experimental manipulation was the number of independent parties that needed to develop components 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.

For this multiparty 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 one- to seven-point Likert scale, ranging from "not at all confident" to "extremely confident." Second, consistent with the previous experiments, 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-subject comparison between an interdependent multiparty case (either the six-party or two-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 ($178 million) to the two ($203 million) to the one-party case ($250 million).

Results

Between-subjects tests of the effect of the experimental condition—six-party project with 75% chance each versus two-party project with 45% chance each—with fixed effects for the executive program included to account for any baseline differences across executive education programs:

Subjective Confidence. First, we examined the dependent variable of subjective confidence in the venture, which ranged from one to seven. Experimental condition had a significant effect on the subjective confidence reported by participants, $t(135) = 2.06$, $p = 0.035$. 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 ($M = 3.06$, $SD = 1.26$, $n = 69$, $SE = 0.15$).

Valuation of Opportunity. Experimental condition also had a significant effect on participants' valuations of the projects, $t(135) = 3.07$, $p = 0.004$. 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 ($M = 138.5$, $SD = 132.18$, $SE = 15.91$).

Within-Subject Comparison with Pure Risky Choice. We also examined the responses in the follow-up single-party case (a 25% chance at $1 billion for their company) as it compared with the responses in the multiparty cases. Participants reported significantly lower subjective confidence in the single-party case ($n = 141$, $M = 2.62$, $SD = 1.22$, $SE = 0.10$) than in the multiparty cases, $t(139) = 4.35$, $p < 0.001$, an effect that did not depend on whether individuals had been in the six- or two-party condition, $F(1, 139) = 1.41$, $p = 0.24$. 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 multiparty project, $t(139) = 5.27$, $p < 0.001$, a difference that was larger in the six-party condition than the two-party condition, $F(1, 139) = 5.31$, $p = 0.02$.[6]

Discussion of Experiment 3

The primary result of Experiment 3 was that executives 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 result extends our earlier findings regarding separate–aggregate presentation to add consideration of the impact of the number of partners involved in a venture. We find that a greater number of conjunctive components, along with their higher separate chances of success, left people more optimistic about the opportunity as a whole even though the aggregate chance of success was worse ($178 million versus $203 million).

Thus far, we have established how pervasive this effect is in terms of its multiple causes and robustness across samples. In the next two experiments, we examine the breadth of this effect by examining two additional decision settings that are common in organizations. Experiment 4 examines the choice of product design in which an individual can increase the potential payout by adding elements to the project with the trade-off that adding elements also increases the likelihood that at least one critical element will fail to be developed. In Experiment 5, we transition to the question and topic of agency and examine how the dynamics explored thus far play out in a coordination game with uncertainty about how much effort one's group members will invest in a joint project.

Experiment 4: Adding Partners

Experiment 4 represents a shift in empirical focus from passively placing a valuation on a potential venture to more actively determining the type of venture being launched. This experiment examined the common real-world decision of determining the level of complexity of the project, specifically, the number of components/parties to include in a risky product development.

This experiment also served three secondary purposes: First, it tested our predictions on a sample of individuals with verifiably high math literacy. Second, it was conducted with real money at stake. Third, it tested whether explicitly reminding participants that (1) the likelihood of conjunctive events is calculated by multiplying probabilities and (2) independent subevents are like separate coin flips would affect their assessment of interdependent opportunities.

Methods

The sample was made up of undergraduate students with a high level of math literacy: students from an Ivy League university at which 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 laboratory 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.

Procedure and Design. 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]

Table 1. Options Available to Participants in the Separate Probability Condition in Experiment 4

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

Participants were randomly assigned to one of two framing conditions, which manipulated whether the options were framed with separate independent probabilities or as a single aggregate probability.

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 the monetary bonus, all independent 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 1.

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 2). 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 typical 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.

There was also a second experimental manipulation: 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

Table 2. Options Available to Participants in the Aggregate Probability Condition in Experiment 4

Option	1	2	3	4	5	6	7	8
Chance of success	75%	56%	42%	32%	24%	18%	13%	10%
Payout	$10	$14	$18	$22	$26	$30	$34	$38

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. Therefore, participants who completed the coin question before the decision-making task would already have top of mind that (1) the chance of a conjunctive event is the product of the chances of the subevents and (2) independence implies that one event occurring does not affect the likelihood that the another subevent occurs as is clear in the case of multiple coin flips.

Results

Product-Design Choice. Overall, there was a significant difference in product-design choices between the separate and aggregate conditions, $t(163) = 3.35$, $p = 0.001$. 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 separate condition, the median option chosen was a design with three components—a 42% chance at \$18—which involves greater risk than the expected value-maximizing option. In the aggregate condition, the median option chosen was the expected value maximizing option, option two: a 56% chance at \$14. Figure 3 shows the distribution of design choices across the two conditions. The choices of participants in the aggregate condition led to 5% higher expected payout than those of participants in the separate condition, $t(163) = 2.80$, $p = 0.01$.

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 heads three times. Interestingly, the effect of framing condition (separate versus 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, $F(1, 161) = 0.0001$, $p = 0.96$. Additionally, there was no main effect of the coin-question timing on design decisions, $t(161) = 0.18$, $p = 0.86$.

Thus, it made no difference whether the coin question prompting participants to consider how to compute

Figure 3. (Color online) The Distribution of Product-Design Choices Across Conditions in Experiment 4

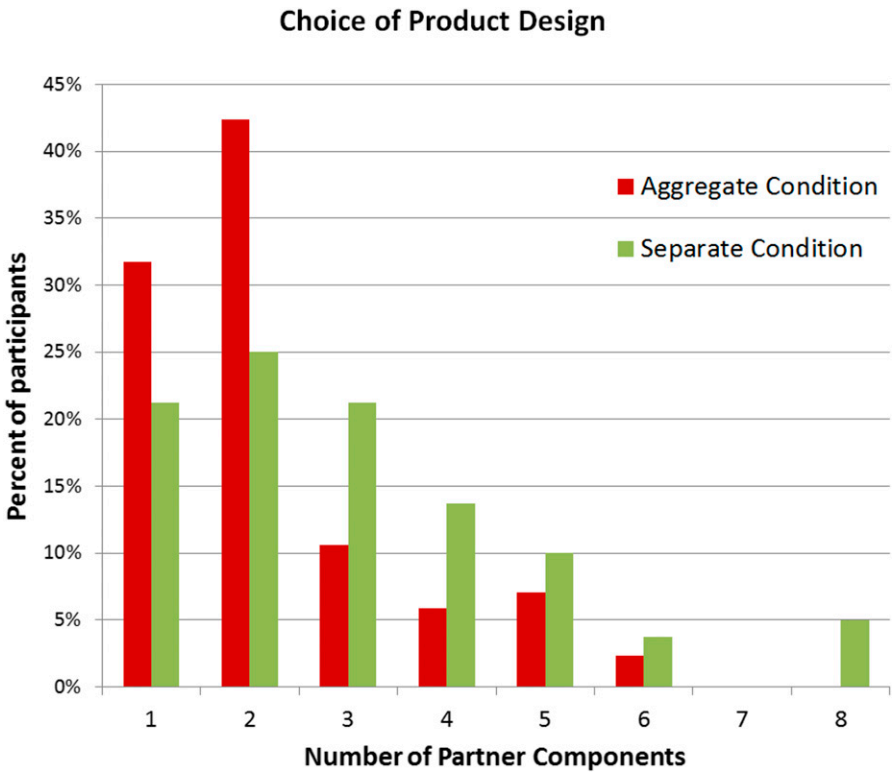
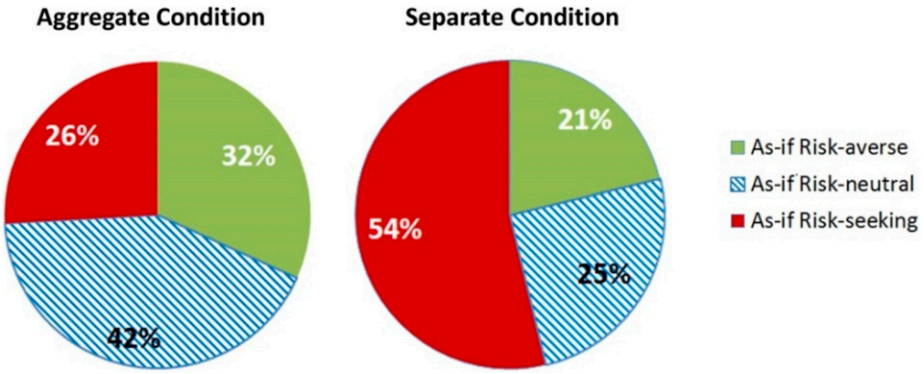


Figure 4. (Color online) Percentage of Choices in Each Condition That Are Consistent with Risk Aversion, Risk Neutrality, and Risk Seeking in Experiment 4



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, the evidence suggests that participants well understood how to compute joint probabilities. Also, heightened awareness of how to compute joint probabilities did not affect their design decisions in either framing condition.

Discussion of Experiment 4

The key result from Experiment 4 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 as a new distributional shape, such as bimodal (see Figure 3).

The separate presentation of conjunctive 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 4, 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 us 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 multiparty innovative ventures when the aggregate chance of success for the project is not explicitly presented to the decision maker.

Experiment 5: Strategic Uncertainty in Partners' Prioritization

In this experiment, we shift from examining decision making when probabilities are fixed and exogenous to a setting characterized by strategic uncertainty and agency. We explore whether, in the face of conjunctive value creation, participants will exert costly effort in the interest of increasing the chance of a higher group payout when the group payout is determined by the lowest contributor. Such settings are often referred to as weak-link (or minimum effort) coordination games, a topic of considerable interest in experimental economics (Camerer and Weber 2013).

As Riedl et al. (2016, pp. 737–738) wrote, "In such problems, each agent has the incentive to coordinate on high efforts, implying high individual and group welfare, but also faces considerable strategic uncertainty, because one single 'trembling' player suffices to cause substantial losses for all." In such a game, an individual makes one's effort decision based in part on one's subjective belief about the uncertain behavior of others. This uncertain behavior is, in effect, strategic risk. Payoffs, in this case, depend not on execution of multiple parts, but on the effort applied to the development of each part. In the real world, both dynamics—coinnovation risk and agency risk—are critical for project success; in this experiment, we extend our study to examine the second element: agency risk within strategic interactions.

In doing so, we also shift to a case in which participants do not know the risk that they face. Rather, they can only form subjective beliefs about the likelihood that other players will withhold effort. As a consequence, we are able to examine our predicted dynamic in a setting with epistemic uncertainty in which the exact parameters of risk are not known rather than aleatory risk, with which the exact parameters of risk are known (Puranam et al. 2012, Tannenbaum et al. 2016). We also note that, in contrast to our previous experiments, in the

weak-link game value creation is not an all-or-nothing proposition.

In this experiment, we introduce agency as well as endogenous beliefs about outcomes. We use the weak-link game structure to frame participants' choices as regarding either (1) their own assessment of the separate, individual choices that their group members are likely to make or (2) an aggregation of these individual assessments into a prediction of group-level behavior. We allowed the perception of risk to be naturally occurring (based on the individual players' own estimates of the likely behavior of the participant pool) and the true degree of risk faced by the players to be naturally emergent (based on the actual choices of the participants with which players were grouped).

Methods

The sample was made up of 124 undergraduate students at an Ivy League university. The sample was 60% female; the average age was 21.1 (SD = 1.67); the most common majors in the sample were economics, engineering, and government. Individuals participated via an online survey, having been contacted by email through a university research laboratory. In return for 10 minutes of their time, they received a payment of between $1 and $13.

Procedures and Design. Participants were informed as follows:

> We are going to randomly group all survey-takers into groups of six. Your group is "collaborating" on a project and each of you needs to independently finish a separate part. The overall project is completed once all of the six group members finish their part. You and each of your group members will need to decide how fast to finish your respective parts. This decision matters for two reasons that work in opposition. First, it's costly to you to work faster on your part. Second, your payoff depends on the slowest group member because the project is only completed once the slowest group member finishes his or her part. The faster the whole project is completed, the more $ all group members earn. For you (and each of your group members), the cost of finishing your respective part depends on the level of priority you give it [see Figure 5]. Each of the 6 group members is separately making this decision for his or her respective part. When a group member chooses a lower priority it lowers their costs, but then their part will take longer. The whole project is completed when the slowest person finishes his or her part. However, the amount of $ each group member earns from the completed project is greater the faster the project is completed [see Figure 5]. When you put the cost and revenue numbers together, the situation—for you and your other group members—looks like the payoff matrix in [Figure 5]. As you can see, you are best off if everyone in your group (including you) chooses high-priority. But if even one other person in your group chooses medium-priority or low-priority, then choosing high-priority would be costly and you would be better off choosing a lower priority level for yourself.

Note that each participant has the incentive to match the lowest prioritization level chosen by their other group members but does *not* have the incentive to make the project a lower priority than the least contributor (Hirschleifer 1983, Van Huyck et al. 1990, Knez and Camerer 1994). For example, if one's other group members all choose to make the project a high priority, then one would be worse off choosing "medium" instead of "high."

What has been described thus far is similar to the payoff structures in existing weak-link research in experimental economics (see Camerer and Weber 2013). Where our experiment differs from past work was in the following step. The participant was asked

> We are having about 120 undergraduates at your school complete this exact same survey and you all know that you will be randomly placed in groups of six. What percent (%) of these students do you think will choose each priority level? [high, medium, low]

Participants allocated likelihood to each option (high, medium, low) such that they summed to 100%. These responses served as a measure of the distribution of choices they anticipated among potential group members.

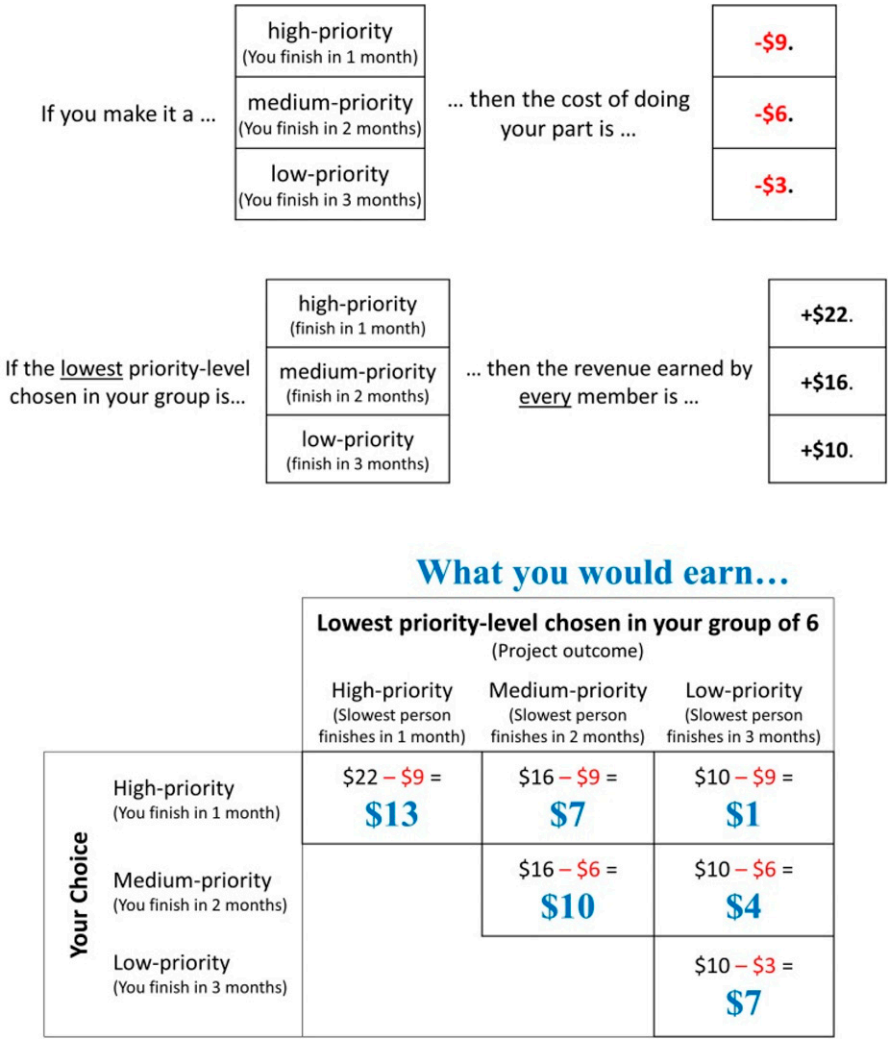
In the *separated-own-beliefs* (control) condition, we showed the participants their own estimates of the likelihoods that other players would choose low, medium, and high effort levels. We then asked them to choose their own effort level: low, medium, or high.

In the *aggregated-own-beliefs* (treatment) condition, we showed the participants their own estimates of the likelihoods that other players would choose low, medium, and high effort levels. We then informed them that, using the estimates they had just made, one can compute an implied estimate of the probability that the lowest priority level chosen among their five randomly selected partners would be low, medium, or high. We then computed and showed them—according to their own reported beliefs about the distribution of choices among all participants—the chance that each of the following cases would occur among their five group members: (1) all five partners choose high priority, (2) no partners choose low priority but at least one chooses medium priority, (3) at least one partner chooses low priority.

As an example, consider the case in which a participant reports that among the 120 participants, the participant expects 50% to choose high, 30% to choose medium, and 20% to choose low. After the participant submits these estimates and before making the participant's own prioritization decision, the participant would see the following:

Both conditions: You reported that, among the whole set of survey takers, you expect

Figure 5. (Color online) The Cost and Revenue Numbers in Experiment 5 and the Ultimate Payoff Matrix as Presented to Participants



- 50% to choose high priority,
- 30% to choose medium priority,
- 20% to choose low priority.

Aggregated-own beliefs condition only: Because you will be grouped with five randomly selected people from the set of 120, we can use your estimates and do the math to see what it means for the probability that the lowest priority level chosen among your five partners will be high, medium, or low. According to your estimates, here is how likely each possible group outcome is among your five partners:

- All five partners choose high priority: 3%
- No partners choose low priority but at least one chooses medium priority: 30%
- At least one partner chooses low priority: 67%

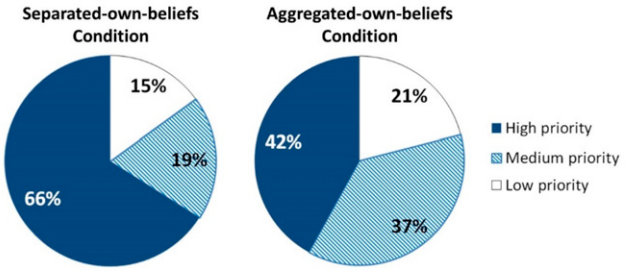
When making their choice, we reminded all participants that, when the survey was done, we would be randomly grouping them with five other survey takers and they would earn money according to their own prioritization decision and the decisions of the people in their group. Figure 5 presents the actual instructions and payoff matrix shown to participants.

Results

The was no significant difference across conditions in participants' estimates of the percentage of other players that they expected to choose high, medium, and low effort levels, $t(122) = 1.47$, $p = 0.14$.

Priority Level Choice. An ordinal logistic regression showed that, as predicted, there was a significant difference between conditions in the priority level chosen for the project ($b = 0.86$, $SE = 0.35$, Wald = 5.93, $p = 0.01$). As shown in Figure 6, in the control condition, 66% of participants chose to make the project a high priority. However, in the aggregated probabilities condition—in which we used the individual's own beliefs about what players would do to inform

Figure 6. (Color online) Percentage of Participants Choosing Each Priority Level by Condition in Experiment 5



them of what five random draws from such a distribution would yield—only 42% chose high priority with the number of individuals choosing medium priority increasing from 19% to 37%.[8]

Discussion of Experiment 5

We show the effect of separate versus aggregate presentations of interdependence in a context defined by agency and strategic choice. In an experiment in which participants were making decisions based on their own subjective assessment risk in a multiparty venture (as opposed to reacting to exogenously dictated probabilities), presenting participants' own beliefs to themselves in aggregated characterizations led them to make more conservative choices.

General Discussion

Any approach to managing interdependence hinges 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 investments. Although no single experiment presented here provides an exhaustive examination of the perception of interdependence, collectively the stylized experiments offer strong support for the proposition that individuals are subjectively more confident and optimistic in an interdependent venture when its chances of success are presented as separate probabilities for each component and that this optimism is exacerbated by a greater number of critical partners.

We approach this phenomenon using a variety of decisions (valuation, design, and prioritization) and a variety of participant types (business executives, undergraduates, and online panels of managers), and the robust findings increase our confidence in the presence of this causal relationship. Across five experiments, we examine how the presentation of interdependence (showing the probabilities for individual components rather than the overall project) and the extent of interdependence (increasing the number of critical partners) affect judgment and behavior. We find evidence of

(1) Inflation of project valuations: In Experiments 1–3, individuals tolerated a higher cost threshold for a potential project when the chance of success was presented in terms of its critical components rather than the project as a whole. In some cases, this effect led to valuations of opportunities that violated the objective of maximizing return while minimizing risk.

(2) Addition of excessive partners to projects: In Experiment 4, individuals increased their dependence on partners, thereby increasing their risk and decreasing their expected return, when presented with the separate chances of success for each partner relative to when presented with the aggregate chance of project success.

(3) Overinvestment of effort: In Experiment 5, individuals engaged in costly prioritization of the development of their part within an interdependent project, failing to sufficiently account for the likelihood of a holdup with at least one partner, thereby hurting their expected return.

With these findings, we explicitly introduce the question of subjectivity in decision making to the ecosystem literature. An important contribution of this paper is the distinction between the constructs of *awareness* of interdependence (identifying all the critical dependencies for value creation) and *perception* of interdependence (the subjective interpretation of this knowledge that underlies the assessment of the overall opportunity). We demonstrate that, even with perfect awareness of interdependencies for value creation, a critical behavioral challenge remains for managers.

We show that the overoptimism that arises in conjunctive settings cannot be fully accounted for by the "mechanical" explanations posited in past psychology literature, namely a reliance on a mental miscalculation because of the lack of capability or motivation to compute the conjunctive probability. We find that overoptimism can emerge via intuitive confidence, whereby mere exposure to the probabilities of success for the critical subevents generates a positive "subjective coloring" to the assessment even when the aggregate probability is known. This is important because it means that, even in high-stakes, real-world settings, greater effort and explicit calculation may not be sufficient to eliminate excessive optimism in conjunctive projects.

Our experiments are highly stylized and would 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 simplicity of the experimental settings positions them as conservative tests for overoptimism. We eliminate real-world considerations, such as 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); and the politics of spreading blame for failure (e.g., wanting more partners involved in case something goes wrong). Indeed, finding strong results of overoptimism in the absence of these possibilities within our stylized settings begs the question of how much more overoptimistic 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) and the introduction of redundancy and disjunctive efforts. Moreover, we expect that interactions between number of partners and other factors—for example, 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, each of which could be the focus of future work.

Our study raises a number of important implications. We are witnessing a near-universal trend for organizations across the economic spectrum—from corporations to nonprofits to governments—to pursue innovation and growth through greater collaboration. In this light, the partnership-rooted bias toward overoptimism 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 overreliance on partners, overinvestment in collaborative initiatives, and the under-management of interdependence. To be clear, the implication of this study is not for managers to avoid interdependent opportunities; rather, it is to make sure that choices about interdependent opportunities are approached with the fullest possible recognition of potential biases and their consequences.

Acknowledgments

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Endnotes

[1] Bar-Hillel's (1973) 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 the feminist movement" as higher than the likelihood that Linda "is a bank teller" (Tversky and Kahneman 1983), a violation of probability theory. This bias has been shown to arise because of the use of representativeness and associative thinking in the formation of category likelihood judgments; 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 representativeness. The conjunction fallacy and questions of categorization play no role in our study or in Bar-Hillel's (1973).

[2] We position our paper in the context of the broader psychology literature in the presentation of Experiment 2.

[3] 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.

[4] For all five experiments, we report two-tailed p-values even for tests of directional predictions.

[5] The filters were the following: reporting that one is willing to read instructions, reporting back the two possible financial outcomes in the scenario after reading the instructions, choosing "disagree" to the statements "Even if this project is costless, our company should not pursue this project" and "Our company should be willing to pursue this project at any cost" (binary), and having internally consistent responses when stating whether nutrition or exercise is more important for health (reported as binary choice and on a slider).

[6] Given that the experiment's primary purpose was to compare the six- and two-party cases across conditions, the single-party case always followed the multiparty case. Although it is possible that individuals were less risk tolerant after already providing a valuation of a previous opportunity for their company, this would not account for the differences between six- and two-party conditions.

[7] Following the choice of product design, participants also had the opportunity to explain their decision in an open-ended response box.

[8] Given all participants' project prioritization choices, expected payments were 16% higher in the aggregated-own-beliefs condition than in the separated-own-beliefs condition, $t(122) = 2.63$, $p = .01$.

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