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Bounded subadditivity in management decisions

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Abstract

Purpose – As subjects irrationally perceive probability changes as more impactful when shifting an event from impossible to possible or from possible to certain, compared to increasing the likelihood of an already possible event, this study examines how workers process success probabilities and whether their resource allocation decisions are distorted by bounded subadditivity.

Design/methodology/approach – We conduct an online randomized experiment with 3,980 employees.

Findings – We detect a certainty effect (upper subadditivity), whereby professionals are willing to devote a disproportionate number of hours to a project when their contribution transforms the success of the initiative from possible to certain rather than increasing the likelihood of success by the same percentage points. We find no evidence of the possibility effect (lower subadditivity), whereby workers would devote a disproportionate effort when their contribution turns a sure failure into a possible success rather than simply increasing the likelihood of success by the same percentage points. We observe a rational tendency to try harder for a greater increase in the probability of success, but only far from the limits of the probability spectrum and not close to the limits.

Originality/value – Attempts to understand bounded subadditivity in management decisions have been incomplete. We disentangle two real-world variables and offer a more refined operationalization.

Keywords Workforce management, Bounded subadditivity, Certainty effect, Possibility effect, Randomized experiment

Paper type Research paper

Introduction

The ability of organizations to fulfill their mission ultimately depends on their employees' intentional micro-level choices, that is, individual choices oriented towards organizational

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goals and objectives. Focusing on the heuristics and biases program, for no good reason, the bounded subadditivity hypothesis is still a largely unexplored phenomenon, especially as far as the management of human resources is concerned (Belardinelli *et al.*, 2021). According to the bounded subadditivity hypothesis, "an event has greater impact when it turns impossibility into possibility, or possibility into certainty, than when it merely makes a possibility more or less likely" (Tversky and Fox, 1995, p. 271). In other words, the subadditivity hypothesis posits that decision-makers tend to irrationally perceive changes in probability as more impactful when they shift an event from impossible to possible (possibility effect) or from possible to certain (certainty effect), rather than when they merely adjust the likelihood of an already possible event. This study follows up on Belardinelli *et al.* (2021) with the aim of overcoming their limitations by disentangling two manipulations that nicely resonate with real-world working conditions – namely, change in probability size and probability bounds – and providing a more faithful test of the subadditivity principle through a refined operationalization. Since management at all levels requires deciding how to allocate limited time and effort across various tasks, it is crucial to understand how workers process information about the likelihood of success in any given activity and whether their resource allocation decisions among competing projects are influenced or distorted by the subadditivity phenomenon. For example, in healthcare admission decisions, professionals are routinely tasked with choosing whether to prioritize patients with high chances of survival or those with lower chances. In healthcare project selection, workers must decide whether to conduct research that improves treatments for already curable diseases or to develop new treatments for currently incurable diseases. Similarly, in strategic healthcare management decisions, managers often choose between investing in best performing hospitals that are close to achieving excellence or worst performing hospitals. While some management scholars have tested the subadditivity principle through laboratory experiments with students (Abdellaoui *et al.*, 2007; Kilka and Weber, 2001; Wu and Gonzalez, 1999), work from the field involving large samples of employees is still lacking, although it would illuminate how the same principle affects behavior within organizations. Time seems ripe to fill this gap, given the potential ramifications of bounded subadditivity on a wide range of management decisions, including the efficient planning and allocation of human resources.

Studies that draw on behavioral insights have contributed to re-emphasizing the boundedly rational individual as the main unit of analysis when trying to understand and explain how organizations work and perform (Lejarraga and Pindard-Lejarraga, 2020; Porac and Tschang, 2013). Applications of this perspective to the study of management can be found across several domains, from the behavioral theory of the firm (Cyert and March, 1963), to agency theory (Jensen and Meckling, 1976), the study of behavioral finance (Barberis and Thaler, 2003), the theoretical perspective of ecological rationality (Luan *et al.*, 2019), or the exploration of behavioral strategy (Powell *et al.*, 2011; Workman, 2012). Scholars in this area have been paying increasing attention to mental shortcuts, which have been the subjects of broad research programs such as heuristics and biases program (Kahneman, 2003; Tversky and Kahneman, 1974), the fast and frugal heuristics program (Cavarretta, 2021; Ehrig *et al.*, 2021; Gigerenzer, 2007; Gigerenzer and Todd, 1999; Guercini, 2012, 2019; Guercini and Lechner, 2021; Guercini *et al.*, 2022), the study of nudging and choice architecture (Thaler and Sustein, 2008), and the investigation of naturalistic decision-making (Klein, 2017). Complementing those streams of research with the impact that bounded subadditivity has on the allocation of employees' time seem necessary and relevant.

This study explores decision-making in resource allocation, focusing on how anomalies and deviations from rational decision-making, in the form of bounded subadditivity, can affect human resource management. We delve into both upper subadditivity and lower subadditivity. The former is expected at high probabilities and triggers a certainty effect, where individuals spend disproportionately more effort to ensure success than to merely increase its likelihood. Conversely, lower subadditivity (possibility effect) is hypothesized at low probabilities, where individuals exert more effort to turn certain failure into possible success than to slightly improve the chance of success. By maximizing the internal and ecological validity of inference, our work provides contributions to both research and practice. On the one hand, we experimentally test an established theoretical principle, namely the subadditivity hypothesis, with a large number of workers. To the best of our knowledge, our study is among the first to simultaneously test both lower and upper subadditivity in the context of real organizations. On the other hand, our work holds the promise of being attractive to practitioners because it has implications for how resources can be efficiently and effectively managed, without wasting them for projects that have good chances of success to begin with. In other words, we do not seek to break new theoretical ground. Rather, we seek to test the bounded subadditivity principle in the context of resource allocation and apply theoretically-defined general behavioral tendencies to the setting of healthcare management.

The study of bounded subadditivity

Behavioral approaches provide management with more psychologically realistic foundations about workers' decision-making processes. Among the main ingredients of a behavioral approach is using the individual as the main unit of analysis. In addition, an important premise of such an approach is that the behavior of individuals is not always consistent with rational decision-making models (Ariely and Jones, 2008; Kahneman, 2011). Scholars in management have paid attention to cognitive biases because systematic deviations from rationality can significantly affect administrative behavior (Barnes, 1984; Cornelissen and Werner, 2014; Curseu *et al.*, 2016). This fast-growing body of scholarship, however, does not fully illuminate how employees make sense of ratios and probabilities in risky choices. A few exceptions include investigations of the proportion dominance effect (Bartels, 2006; Bellé *et al.*, 2018; Erlandsson *et al.*, 2015), the denominator neglect and zero-risk bias (Cantarelli *et al.*, 2020), and how individuals weight probabilities when making decisions under risk or uncertainty (Belardinelli *et al.*, 2021; Choi *et al.*, 2022; Kilka and Weber, 2001).

The study of how individuals process probabilities cannot help going back to the assumptions of expected utility theory (Bernoulli, 1954; Von Neumann and Morgenstern, 1944), which has long dominated the study of decision-making. Expected utility theory predicts that when making a decision, a rational actor weighs the utility of each possible outcome according to its probability of occurrence. However, extant behavioral science studies demonstrate that individuals' decisions can systematically deviate from the predictions of expected utility theory (Kahneman and Tversky, 1979).

To account for empirically observed violations, scholars have expanded expected utility theory and proposed decision-making models that consider individuals' tendency to be predictably sensitive to the environment in which they make decisions (Kahneman, 2011; Thaler and Sunstein, 2008). As a descriptive rather than normative account of decision under risk, prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992) is a widely used framework that tries to explain the observed systematic deviations from rational decision-making models (Edwards, 1996). It suggests that utility does not depend exclusively on the amount of wealth one possesses at any given time, but rather on how that wealth compares to a specific reference point, whether it represents a gain or a loss. Among its core elements, Barberis (2013) also identifies a nonlinear transformation of the probability scale. In particular, the weighting function suggests that decision-makers tend to overweight very low probabilities and underweight moderate and high probabilities. Furthermore, they overweight outcomes that are considered certain relative to outcomes that are merely probable (Kahneman and

Tversky, 1979). Recently, in the context of management studies, Choi *et al.* (2022) have experimentally investigated the relationship between probability weighting and cognitive ability demonstrating that over-sensitivity to extreme – relative to intermediate – probabilities is greater among subjects with lower cognitive scores or whose cognition is interrupted due to time pressure.

The principle of bounded subadditivity (Tversky and Fox, 1995; Tversky and Wakker, 1995) branches out from such a weighting function and draws on models of choice under risk (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992), in which all possible outcomes and their probabilities are known to decision-makers. Specifically, the bounded subadditivity hypothesis posits that "an event has greater impact when it turns impossibility into possibility, or possibility into certainty, than when it merely makes a possibility more or less likely" (Tversky and Fox, 1995, p. 271). Accordingly, contrary to predictions solely based on expected utility (Bernoulli, 1954; Von Neumann and Morgenstern, 1944), an equal change in the probability of success is assumed to have a greater impact when it occurs at the extremes of the probability range rather than in the middle. More precisely, a certainty effect (i.e. upper subadditivity) is expected at the higher end of the probability spectrum, whereby individuals are willing to spend disproportionately more effort to turn the success of an initiative from possible to certain than merely to increase the probability of success by the same amount but without reaching certainty. Symmetrically, a possibility effect (i.e. lower subadditivity) is hypothesized at the lower end of the probability spectrum, whereby individuals would spend disproportionately more effort to turn a sure failure into a possible success than just to increase the likelihood of a possible success by the same amount.

Bounded subadditivity has been used to explain decisions both under risk – when all possible outcomes and their probabilities are known – and under uncertainty – when outcomes' probabilities are unknown (Kilka and Weber, 2001; Wu and Gonzalez, 1999). Empirical work in management finds evidence that is consistent with the bounded subadditivity principle. In two laboratory experiments with university students, Abdellaoui (2000) demonstrated that changes in probability that bite the end points of the probability interval have more impact than the same increments in the middle of the scale. Similarly, Bleichrodt and Pinto (2000) detect probability weighting – both in the forms of lower and upper subadditivity – in the context of medical decision-making. Professionals do not seem to be immune to bounded subadditivity. For instance, in the work of Fox *et al.* (1996), decisions that are in line with bounded subadditivity were found among 88 professional options traders asked to price Microsoft and IBM options, about which they had significant knowledge and experience. As the authors put it, "evidently, years of experience in forecasting price movements of Microsoft or IBM and making trades on the basis of these beliefs were not sufficient to expunge subadditivity" (Fox *et al.*, 1996, p. 16). Adopting a human resource management perspective, Belardinelli *et al.* (2021) provide a partial test of bounded subadditivity by investigating upper subadditivity in a representative sample of the Italian working age population; they show that private sector workers decide to contribute to organizational projects based on projects' probability of success, consistent with the certainty effect. That is, subjects are more likely to join a project in which they are able to provide a small contribution that turns the probability of success into certainty (upper subadditivity) rather than an alternative project in which their participation makes success twice as likely but not certain. Drawing on this body of evidence, we formulate and test the following bounded subadditivity hypotheses.

H1a. Lower subadditivity: Subjects are willing to spend more hours on a job project when their contribution turns the success of the initiative from impossible to possible (i.e. possibility effect), relative to when their contribution merely makes success more likely.

H1b. Upper subadditivity: Subjects are willing to spend more hours on a job project when their contribution turns the success of the initiative from possible to certain (i.e. certainty effect), relative to when their contribution merely makes success more likely.

Among the few studies that simultaneously test upper and lower subadditivity, that is both the certainty and possibility effects, a common result is that the transformation of probabilities seems to have greater impact at the upper rather than at the lower end of the probability spectrum (Abdellaoui, 2000; Tversky and Fox, 1995). For instance, Abdellaoui (2000) demonstrates that "the transformation of probabilities has more impact near certainty than near impossibility" (p. 1507). This finding is consistent with Tversky and Fox (1995). Indeed, Tversky and Fox (1995) find that "the certainty effect is more pronounced than the possibility effect" (p. 272). Hence, we should expect that an event increasing the probability of success of an organizational program from 99% to 100% will be weighted more than the same event increasing the probability of success of the program from 0% to 1%. Based on the existing evidence for the relative strength of the subadditivity effects at opposite ends of the probability range, we formulate an additional hypothesis about the relative strength of the certainty vs. the possibility effects.

H2. The certainty effect (i.e. upper subadditivity) is larger than the possibility effect (i.e. lower subadditivity).

As a final point, it is interesting to investigate how bounded subadditivity and rationality hypotheses interact. As explained above, the former predicts that, keeping constant the percentage increase in the probability of success of an initiative, employees will be willing to spend more hours on the project if the contribution turns the success of the initiative from impossible to possible or from possible to certain relative to when their contribution merely makes success more likely. The latter, instead, predicts that, keeping fixed the initial probability of success of a job project, employees will be willing to spend more hours on the project if their contribution increases the probability of success by a larger amount. What happens when these two effects interact, that is when both the presence of success bounds and the size of the contribution of an employee change, remains an open question that our study aims to address. Put differently, while decision weights might be influenced by factors other than probability itself, such as the presence of the probability interval bounds (either impossibility of certainty), one property of the weighting function is that weights are increasing in probability (Abdellaoui, 2000; Kahneman and Tversky, 1979). Therefore, consistent with predictions of rational models, *ceteris paribus*, a higher probability will have a higher weight than a lower probability. In other words, an event that increases the probability of success of an organizational program from 10% to 20% (i.e. increase in probability by 10% points) would be valued more than the same event increasing the probability of success of the same program from 10% to 11% (i.e. increase in probability by 1% point).

Method

Our study consists of an online randomized experiment with 3,980 professionals working for a regional healthcare system in Italy. Participation was voluntary and anonymous. In designing our research, in agreement with the partner regional government, we opted to prioritize internal and ecological validity of our inference over external validity of the findings. To maximize the internal validity of our inference, we used a randomized experiment, which is the most efficient tool for making an unbiased estimate of the average causal effect of an intervention of some kind (Shadish *et al.*, 2002). As subjects have an equal and nonzero probability of being assigned to any experimental arm, the groups resulting from randomization are probabilistically similar to each other on average. Therefore, any differences in outcome measures among the groups are due to the intervention rather than to any other characteristics, either observed or unobserved. To maximize the ecological validity of our work, we discussed and refined experimental scenarios with key informants in our partner organization in order to assess the extent to which the study setting resonates with naturally-occurring environments (Harrison and List, 2004; Morton and Williams, 2010). Overall, this procedure takes up the call to bridge the science-practice gap that crosses the borders of disciplines and professions (e.g. Guercini, 2004).

Our experimental scenario firstly prompted respondents to imagine that some colleagues were asking them to join an organizational change project. The scenario then provided information on the change in the probability of success, on a 0 through 100% scale, should they decide to join the project. We used a factorial design in which we manipulated two factors, namely the baseline probability and the maximum percentage change in the probability of success in case the respondent joined the project. In our design, the baseline probability of success of the organizational initiative qualifies as a reference point. In fact, it is meant to serve as the position from which participants measure the gain that they can provide by joining the project.

We manipulated the baseline probability of success at fourteen levels (i.e. 0, 1, 10, 30, 40, 48, 49, 50, 51, 60, 80, 90, 98 and 99%) and the maximum change in the probability of success due to the respondent's contribution at two levels (i.e. 1 and 10% points). After being exposed to the scenario, participants were invited to indicate the number of hours they would be willing to contribute to the project by moving a slider ranging from 0 to 100 h.

For the sake of parsimony, we did not use a full factorial design and selected only the 16 out of the 28 possible combinations that were more informative from both a theoretical and practical perspective. As a result, subjects were randomly assigned to one of 16 scenarios that read like the following, in which the baseline probability of success is 99% and the increase in the chance of success in case the respondent joins the project is 1% point:

> Imagine that a group of colleagues invites you to participate in an organizational change project. Without your contribution, the probability of success of the project is 99%. With your contribution, the probability of success can increase up to 100% (certain success). By moving the slider below, indicate how many hours you would be willing to dedicate to the project in the next year, necessarily subtracting them from other activities.

In two of the experimental vignettes, by joining the project, the respondent had the possibility to turn the success of the initiative from impossible (i.e. 0% probability of success) to possible (i.e. 1 or 10% probability of success). In these scenarios, therefore, expending effort on the job initiative meant moving away from the lower bound of probability (i.e. zero). Similarly, in two other vignettes, the respondent's participation in the initiative would turn the success of the project from possible (i.e. 90 or 99% probability of success) to certain (i.e. 100% probability of success), thus hitting the upper bound of probability. In the remaining twelve scenarios, participation in the project resulted in an increase from an initial non-zero probability of success, without ever achieving sure success. In other words, impossible success was the lower bound of the probability range in two scenarios, certain success the upper bound of the probability range in two vignettes, and the range of probability did not include the two extremes (i.e. zero or one-hundred percent) in the remaining scenarios.

The rationale behind this design is to allow testing whether an equal increase in percentage points of the probability of success has a different impact on the willingness of subjects to contribute time to a project, depending on whether their participation can turn the success of the project from impossible to possible, from possible to certain, or merely to make success more likely. This design seems very well aligned to the original bounded subadditivity hypothesis depicted by Tversky and Fox (1995).

Results

Respondents are 71% female. As far as age is concerned, about 16% are younger than 35, 24% are between 35 and 44, 37% between 45 and 54, and 23% older than 54. In terms of job families, 59% are nurses or nurse assistants, 16% medical doctors, 11% administrative staff, 10% allied professionals and 4% do not identify with any of the previous categories. Subjects work in three types of public healthcare organizations, namely 65% in non-teaching hospitals, 20% in local health authorities and 15% in teaching and research-intensive hospitals.

Table 1 provides an overview of the 16 experimental arms to which participants were randomly assigned. Separately for each experimental arm, the table reports the number of subjects, information about our manipulations of the success probability and the average outcome in terms of number of hours along with the associated standard deviation. The four columns in the "Probability of Success" section of the table indicate, respectively, the baseline probability, its increase if the respondent joins the project, the resulting final probability and whether or not the probability interval includes the lower probability bound (i.e. zero percent) or the upper probability bound (i.e. 100%).

Figure 1 provides a graphical comparison of the average number of hours that subjects are willing to contribute to the project in the following experimental conditions.

(1) *Lower Bound*: when the baseline probability is zero with the participant's contribution transforming the success of the initiative from impossible to possible (possibility effect);

(2) *No Bound*: when the probability interval does not include neither the lower nor the upper probability limits and a respondent joining the project merely makes success more likely;

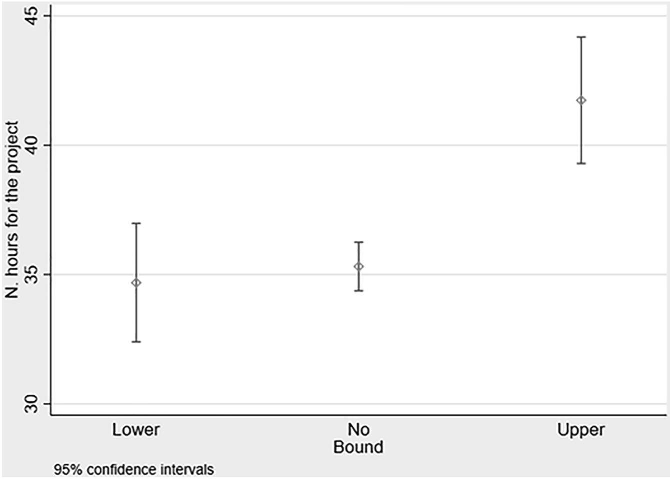
(3) *Upper Bound*: when the final (i.e. baseline + increase) probability is equal to one hundred percent with the participation of the subject that transforms the success from possible to certain (certainty effect).

A series of analyses of variance (ANOVAs) with Bonferroni corrections indicate that the number of hours that subjects in the Lower Bound condition (M = *34.69,* SD = *26.06,* n = *501*) are willing to contribute to the project is not significantly different compared to

Experimental arm	N	Probability of success				M (hrs)	SD (hrs)
		Baseline	Increase	Baseline + Increase	Bound		
1	252	0	10	10	lower	35.58	25.28
2	249	0	1	1	lower	33.78	26.85
3	251	1	1	2	no	28.20	21.96
4	251	10	10	20	no	36.88	24.91
5	248	30	10	40	no	36.84	25.37
6	248	40	10	50	no	38.18	25.07
7	243	48	1	49	no	29.91	24.34
8	245	49	1	50	no	33.79	27.00
9	249	50	10	60	no	39.67	27.54
10	251	50	1	51	no	30.26	25.88
11	249	51	1	52	no	33.39	26.71
12	250	60	10	70	no	38.84	27.31
13	251	80	10	90	no	42.53	26.77
14	245	90	10	100	upper	41.99	27.97
15	248	98	1	99	no	35.13	27.18
16	250	99	1	100	upper	41.49	27.45

Source(s): Created by authors

Table 1. Average and standard deviation of number of hours for the project, by experimental arm



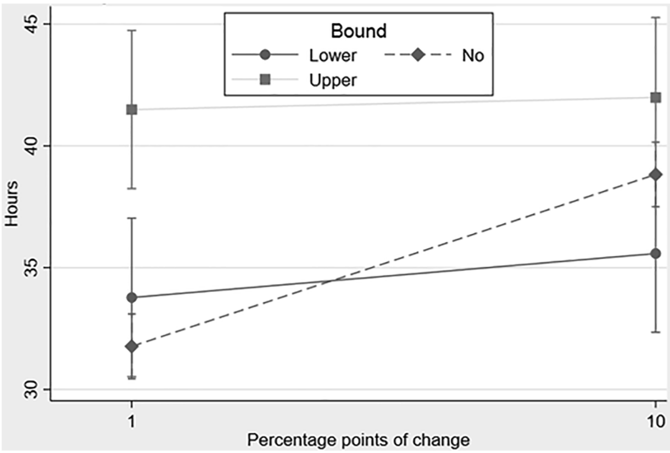
Source(s): Created by authors

Figure 1. Average number of hours that workers dedicate to a job project, by presence of a lower or upper success probability bound

respondents in the No Bound condition (M = *35.31,* SD = *26.17, n = 2,984*), $p = 1.000$. This finding is conflicting with the lower subadditivity expectation stated in Hypothesis 1a. In other words, we do not find any evidence of a possibility effect. To the contrary, our data provide support to the upper subadditivity expectation – i.e. the certainty effect – posited in Hypothesis 1b. Our ANOVAs with Bonferroni corrections show that the number of hours that subjects in the Upper Bound condition (M = *41.74,* SD = *27.68, n = 495*) are willing to contribute to the project is 6.43 higher ($p < 0.0005$) compared to respondents in the No Bound condition (M = *35.31,* SD = *26.17, n = 2,984*). Lastly, Figure 1 displays that our experimental results are consistent with Hypothesis 2 because the number of hours that subjects in the Upper Bound condition (M = *41.74,* SD = *27.68, n = 495*) are willing to contribute to the project is 7.05 higher ($p < 0.0005$) relative to their peers in the Lower Bound condition (M = *34.69,* SD = *26.06, n = 501*).

A regression model reveals a significant interaction between the amount of change in the probability that the project will succeed (i.e. 1 or 10% points) and the bound condition (i.e. Lower Bound, No Bound, Upper Bound) in determining the number of hours that subjects are willing to contribute. As the probability of success moves from 1 to 10% points, the average number of hours for the project increases in the No Bound condition (7.05, $p < 0.0005$) but doesn't significantly vary in neither the Lower Bound ($p = 0.4391$) nor Upper Bound ($p = 0.8423$) arms. Figure 2 provides a graphical representation of this interaction, with the No Bound line being steeper than both the Upper Bound and Lower Bound lines, whose slopes are not significantly different from zero. This suggests that employees' effort appears to be sensitive to the amount of change in the success probability only when the probability range does not include neither the lower nor the upper limit. In other words, the rational tendency to strive harder for greater gains in the probability of success does not seem to hold true at the extremes of the probability spectrum.

Two considerations are worth noting due to their implications for management practice. Firstly, across all three bound conditions, the number of working hours are not proportional to the increase in the probability that the project will succeed. For instance, subjects in the Upper Bound group are willing to spend, on average, 41.49 h for a one percentage point increase in the success probability and only 41.99 h for a 10-point increase. In other words,



Source(s): Created by authors

Figure 2.
Interaction between maximum change in the probability of success of the project and success bounds on the average number of hours that workers dedicate to a job project

whereas the success probability increases by a factor of ten, effort remains the same. Similarly, professionals in the Lower Bound condition are willing to spend, on average, 33.78 h for a one percentage point increase in the success probability and only 35.58 h for a 10% point increase. Again, in the face of a tenfold increase in the probability of success, effort does not change. For subjects in the No Bound condition, the increase in the number of hours from 31.77 to 38.83 due to an increase in the probability of success of one and ten percentage points respectively is still far from a ten-fold increase.

The second consideration that is worth highlighting is that, keeping the change in the probability of success constant, hitting certainty disproportionately increases the number of hours for the projects, thus raising concerns about organizational efficiency. As an example, the average amount of hours that professionals in our sample are willing to contribute to the project is 41.49 for increasing the success probability from 99% to 100% and only 31.77 for an equivalent one-percent increase away from the probability limits. In this case, the certainty effect premium would equal 9.72 h of work. Assuming that the project involves 10 professionals, the certainty premium would cost the organization 97.2 h just because that one-percentage point increase will turn a success from probable to certain rather than make success more likely without reaching certainty.

Discussion

Understanding how employees make decisions about the allocation of their time seems of pivotal importance in the context of workforce management. We conducted our study on a large sample of professionals working for organizations interested in investigating how employees understand and use probabilities in their administrative decisions. In line with theoretical and empirical expectations from previous work (e.g. Abdellaoui, 2000; Belardinelli *et al.*, 2021; Bleichrodt and Pinto, 2000; Tversky and Fox, 1995; Tversky and Wakker, 1995), we detect a *certainty effect* (upper subadditivity), whereby employees are willing to contribute a disproportionate number of hours to a project when their participation transforms the success of the initiative from possible to certain rather than increasing the likelihood of success by the same percentage points. However, unlike previous studies (e.g. Abdellaoui, 2000; Bleichrodt and Pinto, 2000; Tversky and Fox, 1995), we find no evidence of the *possibility effect* (lower subadditivity), whereby workers would be inclined to devote disproportionate time when their contribution turns a sure failure into a possible success rather than simply increasing the likelihood of success by the same percentage points. Interestingly, participants in our sample show a rational tendency to try harder in the face of a greater increase in the probability of success, but only far from the limits of the probability spectrum and not close to the limits. This suggests that the professionals in our study were actively engaged with the experimental task, comprehended it well and could relate to the situation. Taking all results together, our study distinctly reveals the coexistence of rational and predictably irrational tendencies in the behavior of real employees as they make practical decisions regarding the allocation of their working time.

To the best of our knowledge, our study is the first to simultaneously test and compare lower and upper subadditivity effects in the context of human resources management decisions. Moreover, recent attempts aimed at understanding more about how the principle of bounded subadditivity affects workers' daily decisions are only partial (Belardinelli *et al.*, 2021). In particular, our factorial design allows disentangling the effects of two manipulations (i.e. the size of change in the probability of success and inclusion of the upper/lower probability bounds) that were conflated in previous research. Moreover, compared to previous work, which is framed in terms of losses in the probability of success, we provide a more faithful operationalization of the original subadditivity hypothesis, which is framed in terms of increases in the probability of success from impossibility to possibility and from possibility to certainty. This choice not only holds the promise of qualifying as a strict test of the subadditivity principle but also facilitates comparisons and syntheses of studies across disciplinary borders (Holmes *et al.*, 2011).

Another contribution of our work lies in testing the interaction between two experimentally manipulated factors, namely the magnitude of the increase in the probability of success and the presence or lack thereof of the upper/lower probability bounds. In addition to providing the opportunity to make causal claims, testing the interaction of deliberately manipulated variables is highly informative for scholars and practitioners alike. It brings the hypothetical vignettes closer to real-world contexts, where a bunch of elements rather than a single aspect typically affects public administrative behavior. Inexplicably, this type of interaction tends to be less investigated compared to interactions between experimentally-manipulated and observational variables.

Additionally, with just a handful of exceptions, the understanding of whether and how numbers, ratios and probabilities predictably affect professionals' decisions is still at its infancy in management research. For instance, Cantarelli *et al.* (2020) demonstrate that the propensity to implement a new program in an organization is affected by the absolute frequency of similar institutions that have implemented the same program, although the relative frequency is held equal. Furthermore, they find that when deciding between two vaccination plans for two nations, a significant proportion of healthcare professionals irrationally opt for the intervention that saves fewer lives but entails full vaccination coverage in one nation over the intervention that saves more lives overall though not reaching full immunization in either nation. Our work shows that bounded subadditivity might play a role in shaping professionals' behavior. More in general, our results point to the relevance of considering how workers make sense of numbers, ratios and probabilities. They serve as a call to investigate these dynamics more systematically and they should be tested against different contexts, domains, samples and operationalizations, so as to increase the external validity of our findings. For instance, one open question worthy of further exploration is to systematically and rigorously examine how different contexts might moderate the effects of bounded subadditivity on human resource allocation, even beyond the time resource.

Relevance for managerial practice

Our work generates evidence and knowledge that is useable for practitioners, hence joining the efforts to close the science-practice gap that some management scholars regard as one of the grand challenges of the 21st century (Guercini, 2004). As an example, the average amount of hours that professionals in our sample are willing to contribute to a project is 41.49 for increasing the success probability from 99% to 100% and only 31.77 for an equivalent one-percent increase away from the probability limits. Organizations usually have to manage a portfolio of projects with different prospects of success. From an organizational point of view, in expectation, one percent increase in success probability is worth the same regardless of whether probability limits are involved. Managers in complex organizations might want to avoid waste of resources and employees' energy for projects that have good prospects to begin with. Our findings suggest that it might be effective not to make explicit the initial probability of success of organizational projects (or initial probability of survival of admitted patients). Another possible practical implication for managers in organizations is to incentivize participation into projects with worse prospects in absolute terms but with more room for improvement in relative terms, for example by means of performance appraisals and rewards. From another perspective, bounded subadditivity cautions against creating incentives that reward only success. Given the natural tendency to disproportionately prioritize certain success, incentives that exacerbate this tendency may be detrimental to organizational outcomes.

Additionally, training employees on bounded subadditivity in effort allocation can be a powerful device in trying to improve resource use and explicitly identifying priorities without giving in to unintentional behavioral tendencies. For example, in healthcare admission decisions, the certainty effect might lead professionals to prioritize admitting patients who will be saved or recover for sure, while the possibility effect might make them more likely to admit those who would have no chance of survival or recovery unless they are admitted. Moreover, in healthcare project selection, the certainty effect might lead workers to prioritize research initiatives aimed at transforming diseases from treatable to fully curable. Meanwhile, the possibility effect could encourage a focus on research programs that convert previously incurable diseases into curable ones. In strategic management decisions, then, the certainty effect might lead managers to prioritize allocating effort and resources to best performing third-level hospitals (such as highly specialized or university hospitals) that are close to achieving excellence. Meanwhile, the possibility effect could make them more likely to support worst-performing first-level hospitals (such as basic or community hospitals) and second-level hospitals (such as provincial or district hospitals), which would have no chance of even improving service delivery without additional resources. Such decisions should result from a deliberate assessment of trade-offs, rather than intuitive thoughts formed through automatic responses to environmental complexity.

Finally, our evidence brings attention to the breadth of tools available to policy makers and managers in organizations, who can alter employees' choices by enlisting their interpretation of probabilities. Our results resonate with nudge theory (Thaler and Sunstein, 2008), which investigates how the choice architecture has an impact on the quality of decision-making. In this respect, the certainty effect that we experimentally observed is a prototypical example of those supposedly irrelevant factors to which Econs are immune but that may significantly influence Humans' behavior. In our specific case, organizations and their managers should take appropriate measures to counterbalance their workers' preference for projects in which their participation can guarantee a success that is already very likely from the start, rather than for projects where their contribution would be more useful because it could increase by a larger amount an initially lower probability of success.

Conclusion

Our empirical research contributes in three main ways to the advancement of decision-making in management and organizations. A first contribution of our work lies in putting a well-established theoretical principle to a novel experimental test with a large sample of workers. According to the Harrison and List's (2004) taxonomy, our work qualifies as a framed field experiment because it involves real workers performing a decision task that resonates with their naturally-occurring environment. Framed field experiments score higher on realism compared to conventional laboratory experiments, which employ "standard subject pool of students, an abstract framing, and an imposed set of rules" (Harrison and List, 2004, p. 1014). Thus, our work improves the ecological validity of previous experimental tests of the bounded subadditivity principle – which have mainly relied on laboratory experiments – by demonstrating that the certainty effect may significantly bias the decisions of actual professionals allocating their working time across projects.

Our second contribution is to the management of human resources in organizations and lies in testing the interaction between two experimentally-manipulated factors, namely the magnitude of the increase in the probability of success in case of participation in the project and the inclusion or lack thereof of the upper/lower probability bounds. In addition to providing the opportunity to make causal claims (Shadish *et al.*, 2002), testing the interaction of deliberately manipulated variables is highly informative for scholars and practitioners alike. It brings the hypothetical vignettes closer to real-world contexts, where more than one element typically affects behavior. In our work, the choice to intentionally manipulate the size of individuals' contribution alongside the probability bounds allows uncovering the coexistence of more or less rational decisions. More precisely, our interaction analyses show that participants provide answers in line with the predictions of expected utility theory when deciding away from the probability extremes. On the contrary, the subadditivity effect kicks in when the same decisions are made close to the bounds of the probability spectrum. In sum, we observe behavioral patterns consistent with both rational models and the predictably irrational perspective. In so doing, we meaningfully extend and overcome some limitations of previous work on bounded subadditivity in management decisions (Belardinelli *et al.*, 2021).

Thirdly, our evidence expands the current scope of management research on prospect theory, from being mostly focused on its loss aversion component (Kotlyar and Karakowsky, 2007; Schwartz *et al.*, 2008; Wu, 2022) to also addressing the impact of probability weighting. This attempt is nicely aligned to scholarly recommendations that advocate a more comprehensive application of prospect theory to the investigation of management issues (Holmes *et al.*, 2011). Future experimental work may explore the interaction between bounded subadditivity and other key components of prospect theory. It would be interesting, for example, to test whether the certainty and the possibility effects change depending on whether scenarios are framed in terms of probability of failure/loss, rather than probability of success/gain. Investigating how the principle of bounded subadditivity holds when workers face uncertain prospects is still an open question. Precisely, this line of research may stem from cumulative prospect theory, which extends the original version of prospect theory along several dimensions including the accommodation of continuous – rather than solely finite – distributions of outcomes and uncertainty (Tversky and Kahneman, 1992). More broadly, our work connects to scholarship on heuristics and their declinations that span from the most traditional heuristics and biases program (Kahneman, 2003; Tversky and Kahneman, 1974) to recent and far-reaching theorizing on fast and frugal heuristics (Gigerenzer, 2007; Gigerenzer and Todd, 1999; Guercini *et al.*, 2022; Guercini and Lechner, 2021; Guercini and Milanesi, 2020). Although systematizing and reconciling theoretical and empirical work on decision-making processes under risk – i.e. when alternatives, probabilities and outcomes are known – or under uncertainty – i.e. when alternatives, probabilities and outcomes are not known – goes beyond the scope of the current project, it is worth mentioning two schools of thoughts on the impact of heuristics in the two domains. In risky situations, the simplification generated by heuristics may predictably lead to suboptimal estimations because decision-makers tend to disregard pieces of information that, however, would be enough to make an optimal decision. Hence, mental shortcuts lead to biased decisions under risk (Kahneman, 2011). In uncertain situations, the simplification generated by heuristics systematically may lead to optimal decisions because individuals tend to rely only on the most robust pieces of information, among those that are available and are not anyway enough. Hence, mental shortcuts lead to superior decisions under uncertainty (Gigerenzer *et al.*, 2022).

Our work is not immune to the limitations that affect all online randomized controlled trials of the same kind. Thus, we warn professionals to evaluate and use our findings for organizational practices in light of the main shortcomings presented below. Firstly, randomization is the gold standard for estimating the average treatment effect of an intervention and in establishing causal connections between the manipulated independent variables and the outcome of interest. Our research design, however, is unable to unveil the causal chain of mechanisms through which the effects we observe come about. On the one hand, we can make causal claims about the impact of the baseline probability of success of a job project and the maximum change in the probability of success should the employee contribute to the project on the number of hours that they would dedicate to the initiative. On the other hand, though, we are unable to explain the cognitive processes that underlie such impact. Indeed, while randomized experiments are well suited for testing causal relations between variables (i.e. molar causation), standard experimental designs do not necessarily help illuminate the chain reaction linking causes to their effects (i.e. molecular causation) (Shadish *et al.*, 2002). Other experimental designs, such as parallel or crossover designs (Imai *et al.*, 2013), and non-experimental research are better equipped to illuminate such processes. Another main shortcoming of our work lies in a series of potential threats to the external validity of our inference. For example, as already mentioned, it remains to be tested to what degree our findings extend to employees in other industries, healthcare professionals in other countries, different treatments, different outcome variables and full-factorial research designs. Lastly, albeit we designed our experiment with key informants in our partner organizations, other research designs, such as natural experiments, might be better suited to reassure potential ecological validity concerns.

To conclude, our work may be valuable for both scholars and practitioners who are interested in applying the multi-faceted tenets of prospect theory (Kahneman and Tversky, 1979) in the management of organizations. In fact, whereas most of the experiments on how individuals process probabilities and interpret risk come from laboratory settings (e.g. Abdellaoui *et al.*, 2007; Choi *et al.*, 2022; Kilka and Weber, 2001; Wu and Gonzalez, 1999), experimental work that allows testing the same dynamics within organizations, in real-world working conditions, is rather novel and might bear fruit for the societal good.

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