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The Objective Value of Subjective Value in project design negotiations

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ABSTRACT

Design in infrastructure public–private partnerships (P3s) involves integrative bargaining. This research looks at the cognitive and psychosocial experience of designers as the dependent variable in such design negotiations. In this study, we associate designers' Subjective Value (SV) outcomes – psychosocial effects such as trust and rapport – with Objective Value (OV) outcomes – economic payoffs of technical design choices. We conducted a design negotiation exercise with treatment and control settings for the conceptual design of a large infrastructure P3 project. Both the public and private participant's objectives were represented in the exercise. The setup tested the effects of two design mechanisms, communication (dialogue) and common knowledge (reduced information asymmetry) on the understanding and SV perceptions of a large number of designers. In particular, we addressed how these designers perceived their understanding of the complex design problem evolve during the design negotiation exercise, and their psychosocial experience of the change in understanding. We also linked their subjective emotional experience to the degree of agreement in design choices. Participants used a real-time tradespace and visualization model to explore and refine designs while negotiating. The tradespace model tracked not only design trials but also every negotiated, agreed upon design outcome. These design choices generated the OV outcomes of negotiated design. Detailed pre-experiment and post-experiment surveys tracked psychosocial and emotive outcomes using an established scale called the Subjective Value Inventory (SVI), as well as other indicator scales. We found that designers overwhelmingly reported high SV scores, which are positively correlated with both their improved understanding of the design problem and their degree of agreement on design choices after the design negotiation. The OV of enhanced psychosocial outcomes, i.e. positive emotive effects, as a result of early stage design negotiations is thus the important relationship foundation for future rounds of engagement between the same actors in long-lived arrangements such as negotiated P3s, especially since P3 participants may not previously have had a history of or opportunities for establishing trust and credibility.

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Introduction

Design negotiations in infrastructure public–private partnerships (P3s) are an example of non-zero sum integrative bargaining. The partners in this project structure must each choose designs that meet their own objectives. When their preferences do not align, they negotiate to find agreement. In integrative agreements, negotiators reconcile competing objectives to find solutions of higher joint benefit (Bazerman *et al.*, 1985). Since project partners have different roles, expertise, and information, they can be creative and design new arrangements to meet their needs. These new solutions have the potential to improve project value over that of a tightly specified design that any of the partners may have previously independently devised. We define this type of integrative design process *negotiated collaboration*, because it involves joint creativity and bargaining.

In this research, we look at how individual project designers experience design in the context of negotiated collaboration. A designer's experience of design is important because it ultimately affects the designer's and therefore the project's choices. For example, Hernandez *et al.* (2007) found that in complex design problems, 70–80% of eventual system cost is a consequence of design choices made during the conceptual stage of the design process. A deeper understanding of a designer's experience and choices could help structure design processes to more effectively mold a project's trajectory. We therefore select the individual designer as the unit of analysis.

This paper focuses on the issue that constructs such as a designer's understanding of a complex design problem and psychosocial experience in the design process are mostly ignored as dependent or outcome variables in project organization studies, or at best treated in isolation

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because they are transient and difficult to measure. Yet, these dimensions can either enhance or undermine rapport, trust, credibility, and legitimacy of the relationship between negotiating actors. Further, these relational aspects may be associated with the type and quality of the collaborative exchange between negotiating designers. A dialogue-heavy design process may help build more trust through rapport, whereas a process that emphasizes the exchange of technical information and facts may lead to trust through improved technical understanding, but not necessarily rapport in the relationship. The collaboration mechanisms of dialogue and information exchange are often left coupled in the literature. We treat them separately. In short, we therefore ask: How do communication (dialogue) and common knowledge (through technical information exchange) in the project design negotiation affect a designer's psychosocial experience? Is this experience associated with how the designer's understanding of the design problem evolves? How does it relate to the degree of agreement in the integrative bargain? In each of these questions, the constructs of understanding and psychosocial experience are explicitly measured as dependent variables.

Adopting the approach in the literature on the social psychology of negotiations (Curhan *et al.*, 2006), we stylize the outcomes of project design negotiations into two broad types, Subjective Value (SV, psychosocial effects on designers) and Objective Value (OV, techno-economic payoffs of chosen designs). We measure the two types in a controlled design experiment, and show that individual designers were likely to have a positive psychological experience when their understanding of the complex design problem improved through dialogue with each other, and also when they were able to agree on design choices through integrative bargaining. The psychosocial outcomes associated with improved understanding and agreement are a greater degree of rapport, trust, and credibility among negotiating designers, which, in turn, are objectively valuable in long-run infrastructure projects.

Conceptual overview

Early stage project design requires designers to solve a complex problem with competing objectives and trade-offs. After exploring many possible design solutions, designers must make decisions jointly to ensure that the chosen design will meet the competing needs. Designers rely on information exchange and communication not only to develop their own understanding of the complex problem, but also to develop a shared understanding of counterparty objectives and negotiate choices. When human designers negotiate with each other in real time, however, they experience emotional and social psychological effects which are transient and fleeting. We discuss the literature that shapes our research hypotheses and research design for studying the psychosocial effects on designers as dependent variables in design negotiation.

Problem complexity and learning

The complexity of a design problem affects designers' ability to learn and to solve the problem. The number of variables and their degree of coupling, i.e. interdependence between variables, measure problem complexity. Learning is the process of embedding relevant schemas, i.e. the recipes for solving problems (Lawson, 2004). Complexity imposes a cognitive load on designers, affecting their ability to learn. For example, Hirschi and Frey (2002) found that as the degree of coupling in a problem's variables increases, the time taken by designers to solve it increases geometrically. Flager *et al.* (2014) in turn found that coupling becomes less important as the scale of the problem (number of design variables) increases. Instead, solution quality decreases sharply as scale increases. The project design process must therefore account for the effects of complexity on designer's ability to learn and then make design choices. Devices such as calculators or computer models that automate standard routines, or aids such as documents or computer files that store information reduce the cognitive cost in problem-solving. In design negotiations, aids such as computational simulation models and the repeated use of the models can thus help with cognitive load reduction and learning.

Shared understanding

To negotiate, designers must first develop a shared understanding of the design problem. Mental models are one way to capture and describe designers' shared understanding (Badke-Schaub *et al.*, 2007). In multiple designer or team design situations, interaction and collaboration can lead team members to converge on a single problem-solving outcome (Fiore *et al.*, 2010; Reiter-Palmon *et al.*, 2012). In other words, designers adopt a common mental model, or a similar view of a technical problem, and transform ideas into a creative solution.

Communication and information exchange in collaborative design

Designers' mental models depend on whether the individuals work independently or collaborate. Dong (2005) and Wood *et al.* (2014) find that collaborating designers had mental models that were more similar than those of independent designers. Collaboration also decreased fixation, the tendency to focus on a subset of features or ideas, and led designers to think openly about possible solutions. Collaboration can thus increase shared understanding between designers. Conversely, information asymmetry can bias designers' mental models. Austin-Breneman *et al.* (2014) show that designers behave strategically while negotiating design trade-offs. They hedge their future needs by representing their view of the problem conservatively and through 'worst cases'. The mechanism of information exchange becomes critical in problem-solving when designers do not have common information and have competing objectives (Honda *et al.*, 2015).

Information exchange in design is deeply connected with communication. Designers could use the mechanisms of either dialogue or objects (or both) during design collaborations to develop shared understanding. Dialogue, i.e. designers' words and expressions, contains information relevant to the problem they are solving. Objects such as written documents, proposals, charts, and presentations deliver information without requiring dialogue. Designers may, however, need to actively engage in dialogue over these objects and seek clarity to truly understand their meaning and importance. On the other hand, too much information can also be burdensome and fail to improve design outcomes (Clevenger *et al.*, 2013). Further, designers may intentionally withhold or bias information in some competitive situations when there is no way to reveal facts. While face-to-face communication can be important, designers may use computer-based collaboration spaces or methods to support one or both information exchange and communication, when colocation is infeasible (Ostergaard *et al.*, 2005).

Psychosocial effects in negotiation

Negotiations have psychological effects, and can change the resulting economic payoffs and the quality of the interaction between negotiators (Simon, 1987; Bazerman *et al.*, 2000). Negotiations thus have two types of outcomes: economic and psychosocial. The first type, economic outcomes, is the terms of the agreement struck by the negotiating parties. For example, Neale and Bazerman (1985) studied the effect of framing and overconfidence on outcomes in terms of economic gains and losses between managers and unions. The negotiation setting, i.e. the number and identity of people on each side, their incentives, deadlines, and other environmental factors, and individuals' attributes are known to influence economic payoffs (Thompson, 1998; Elfenbein *et al.*, 2008; Sharma *et al.*, 2013).

The second type of negotiated outcomes, social psychological outcomes, is the attitudes, perceptions, and emotions of the negotiators (Thompson and Hastie, 1990; Thompson, 1998). These subjective outcomes receive little to no attention as the performance variables of negotiations because they are fleeting, and hard to assess. Only in the last decade have researchers formalized the study of social psychological factors as outcome measures, instead of predictors of economic outcomes (Walsh *et al.*, 2003; Curhan *et al.*, 2006; Bendersky and McGinn, 2010). This recent work suggests that the SV of social psychological outcomes of negotiation is just as, if not more important than the OV of economic outcomes. Curhan *et al.* (2006, p. 494) developed the construct of SV, which they define as the 'social, perceptual, and emotional consequences of a negotiation'.

SV in negotiated agreements for design is important for at least four reasons. First, negotiators often place high value on the degree of respect or favourable relationships, sometimes even more than the value they attribute to economic payoffs. Social psychological outcomes thus have intrinsic value. For example, when given the choice, negotiators often describe the negotiation objective with frames that signify fairness and respect even if they may secure lower monetary outcomes (Blount and Larrick, 2000). This imbalance may be conscious or unconscious. Second, individuals or entities may be sought out as good counterparts based on the strength of the relationship and credible reputation (Curhan *et al.*, 2006, 2010). The desire to deal with partners who have established rapport may serve to further enhance SV (Tinsley *et al.*, 2002). Third, securing high SV in the first round of a negotiation may lead to both higher SV and OV in subsequent rounds (Drolet and Morris, 2000; Curhan *et al.*, 2010). Finally, enhanced SV can serve as a means of commitment to honour the terms of the agreement, when outcomes are not self-enforcing or easily monitored (Ferguson *et al.*, 2008; Curhan *et al.*, 2009). Curhan and Brown (2011) call this the 'insurance policy' function of SV. For the reasons described here, the relational view of negotiation (Gelfand *et al.*, 2006) may sometimes take precedence over the rational view (Bazerman and Neale, 1992).

Mental models in negotiation

Mental models (or the cognitive representation of the negotiation) and negotiation structure are reciprocal: structure influences mental models and cognitive perception shapes structure and behavior (Bazerman *et al.*, 2000). One relevant cognitive bias is the 'Fixed Pie' effect in which negotiators may falsely assume that the available payoffs from negotiation are constant sum – the size of the so-called pie is fixed (Bazerman *et al.*, 1985). They miss opportunities for integrative bargaining – identifying mutually beneficial trade-offs – that increase the size of the pie (Fukuno and Ohbuchi, 1997). Thompson and Hastie (1990) suggested that some negotiators modified their 'Fixed Pie' perception early in the negotiation to account for the bias; and for those who did not, the bias persisted throughout. Negotiators often behave egocentrically; they misattribute (Gilbert, 1994) and overestimate the ideological difference or incompatibility of interests of others (Keltner and Robinson, 1997) or ignore their perspectives altogether (Valley *et al.*, 1998) and overlook valuable information based on a belief that the counterparty is overstating its case (Bazerman and Carroll, 1987; Tsay and Bazerman, 2009).

Individuals' perception of their role also alters mental models. Montgomery (1998) showed that in negotiation situations with the same economic structure, individuals behave differently depending on the meta-rules of their roles. The same individual may also modify behavior depending on how they perceive their role changing in different situations. How negotiators understand and define the game for themselves can thus be a critical determinant of how they engage.

Shared understanding in negotiation

Asymmetric mental models do not always persist over the course of the negotiation interaction. Negotiators eventually create a shared understanding of the situation, their perception of other negotiators, and the rules of engagement (Messick, 1999). This phenomenon and its effects are what we want to study in terms of designers' psychosocial experience, as they may create a positive design experience.

In contract settings with negotiations, a perceived lack of respect or a veneer of opportunism can jeopardize the relational arrangements between government agencies and private firms. Many authors point to trust as a key element of negotiated decisions in this space (Smyth and Edkins, 2007; Smyth and Pryke, 2009). Relational approaches to contracting therefore emphasize a longer term view of bargaining with an emphasis on collaborative mechanisms for securing outcomes (Rahman and Kumaraswamy, 2004; Osipova, 2014; Suprapto *et al.*, 2014). The SV outcomes of negotiation thus have implications for project design outcomes and the project trajectory as a whole.

Research hypothesis

For designers to reach agreement in the project design negotiation, they must develop a shared understanding of the design problem, defined as an understanding of both one's own and the others' objectives. They must also comprehend the relationships between design choice and expected project performance. Developing a shared understanding also requires actors to reconcile their own interests with those of the negotiation counterparty. In other words, designers' mental models must become similar over time. Designers learn by searching for relevant information, and by observing how changing design variables translates to performance changes. Communication (dialogue) and information exchange are the additional cognitive mechanisms necessary for shared understanding to develop.

We therefore posit that by engaging learning, dialogue, and information sharing, designers make a number of moves and counter-moves to propose design choices until they approach agreement. As a result of this process, a designer's degree of shared understanding is influenced by the type of collaboration exchange between counterparty negotiators. Further, the degree of understanding and the degree of agreement with a counterparty designer are positively related to a designer's psychosocial experience. These beliefs can be further specified as the following three testable hypotheses:

> H1 – Collaboration: relationship between SV and design collaboration mechanisms

The ability of designers to engage in dialogue (communication) or to exchange technical information (achieve common knowledge) could differentially affect SV. This hypothesis is tested by looking at the statistical difference in SV between two different treatment groups (see Research Design section).

> H2 – Understanding: relationship between SV and improvement in designers' understanding

The more that designers learn and understand about a problem in the design negotiation process, the more likely they are to experience positive emotional effects as a result of the negotiation. We test this by looking at the correlation of SV with the improvement in designers' understanding after negotiation across treatment groups.

> H3 – Agreement: relationship between SV and degree of agreement (Objective Value)

The more that designers can agree on the different elements of a project's design, the more likely they are to experience positive emotional effects as a result of the negotiation. SV is correlated with the degree of agreement in design choices across treatment groups to test this hypothesis.

Research design

We created a stylized infrastructure P3 project design setting. Human designers played the roles of the public and private actors in a design exercise with multiple rounds of design and negotiation. The designers used a tradespace computer model to explore design choices. Data were collected through design trials, communication transcripts, and pre- and post-experiment surveys. In this paper, we mostly analyse pre- and post-experiment survey results to address our research questions.

Design setting

The P3 project is a large desalination facility, which uses energy to transform saline water into potable water. A Water Authority contracts with an engineering Firm through a Water Purchase Agreement. The Firm is the agent in this problem; it designs, manages, and supplies water to the Authority, who is the principal. The Authority wants reliable water supply and makes contract payments to the Firm in return for this service.

The technical configuration of the facility affects how the project creates value. Under conditions of demand uncertainty, the reliability of the project is defined as its ability to deliver water as and when demand arises over time. Some design configurations may be more reliable in meeting demand than others, and at different cost and profit conditions, which leads to trade-offs in design. For example, large integrated plants can meet high demand and are expensive, but less flexible to operate than phased plants, which may have lower costs.

The long-term concession agreement in the P3 creates a mechanism for the exchange of value between the two project actors. It also governs how risk affects the principal and the agent. For example, the contractual price terms and other provisions determine the payments that the water authority makes to firm. The contract may also include risk allocation mechanisms such as minimum income guarantee provision in a take-or-pay structure to mitigate the demand risk to which the project is exposed. Figure 1 depicts the roles and interests of the project actors and the terms of exchange in the concession agreement.

Each of these actors has different objectives and perceives the value of designs accordingly. The principal wants to ensure the public interest. As a Water Authority, it desires reliable water supply and is willing to make contractual payments in return. It trades off payments for reliability, i.e. higher reliability comes at the

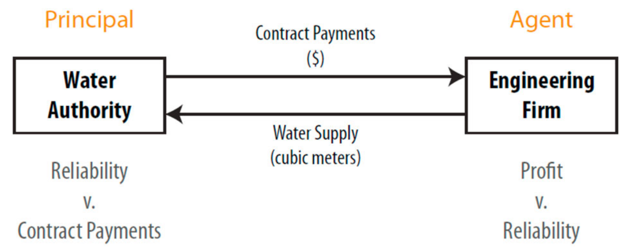

Figure 1. A stylized design setting for a desalination infrastructure P3.

cost of higher service payments. On the other hand, the agent's objective is profit. It is willing to deliver a reliable water supply for profit. The Firm gives up profit to increase reliability. There are thus three ways to express OV (or techno-economic payoffs) in this problem: contractual payments, profit, and reliability. SV denotes the principal and agent's psychosocial outcomes. SV captures phenomena such as sense of self, rapport, trust, and satisfaction from the design process, and these dimensions are common to both the public and private actors.

Tradespace model

To allow designers to explore designs and assess tradeoffs during negotiations, we developed DesalDesign, a computational tradespace model. A tradespace model visualizes how a change in design (movement in the design space) affects performance along multiple dimensions (design trade-offs). The DesalDesign model can simulate lifecycle performance outcomes of chosen designs in a matter of seconds. Figure 2 shows a sample of outputs from the tradespace model, i.e. the OV outcomes for each partner. It shows that for a given level of reliability (>95%), the Water Authority must increase payments for the Firm to be able to earn a higher profit, and that there are different plant configurations and price levels that satisfy these conditions.

For the design exercise, participants used a version equipped with a user interface (Figure 3) to allow a human designer to select designs and read the graphical and tabular outputs. Designers could modify two technical design variables (plant size, number of plant phases) as well as two contractual variables (water price, minimum income guarantee) for a total of four 'degrees of freedom' and observe the payoffs (OV outcomes) being updated in real time. By quickly performing complex calculations, the tradespace model reduces cognitive load enables designers to focus on learning and collaboration.

A common tradespace model can serve as a boundary object (Iorio and Taylor, 2014) when trade-offs are

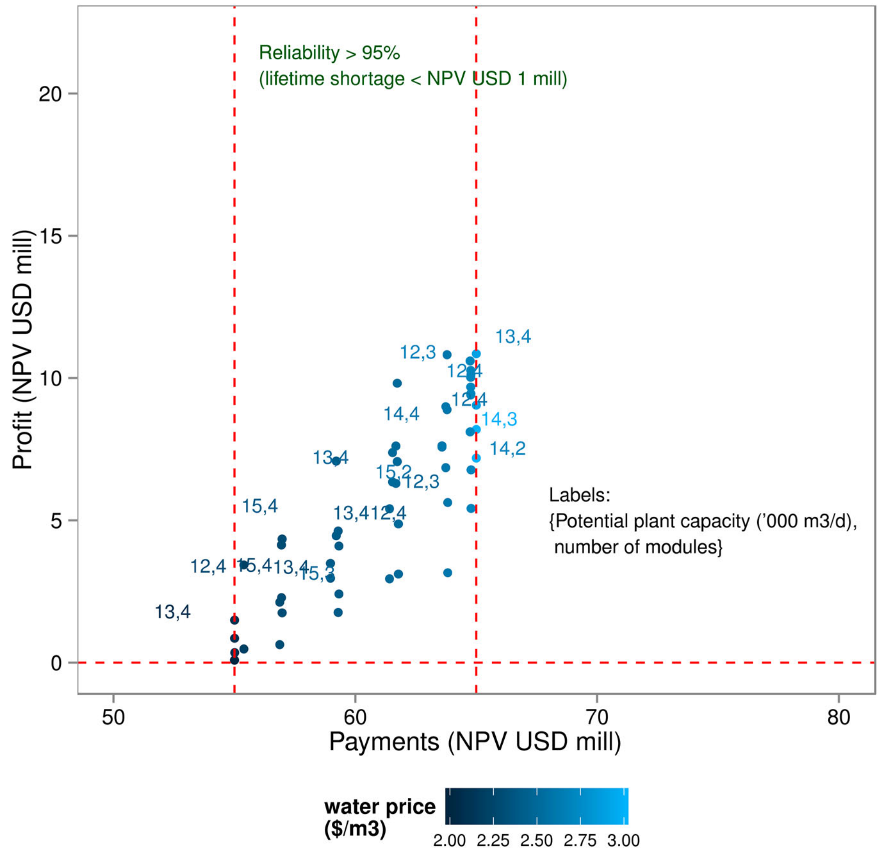

Figure 2. Sample of value outcome trade-offs from the DesalDesign model.

denoted in terms of payoffs to both project actors in the design negotiation. In other words, the tradespace boundary object is a common calculator that shows outcomes not only in terms of a designer's own OV outcomes but also those of the counterparty, thereby reducing information asymmetry and increasing common knowledge.

The DesalDesign tool records every design iteration (trial) that a designer attempts, along with process information such as time stamps. It also records design choice 'submissions', the final design a collaborator may choose in response to a design task. These data are saved for later analysis to compare whether counterparty designers agreed on final design choices in their negotiations.

Design exercise

A large number of engineering designers ($N = 140$) were invited to participate in the design exercise, following Institutional Review Board procedures. About 90 subjects participated 'onsite' on a university campus, and 50 participated using a remote virtual connection. Of these, 112 participants fully completed the exercise, and we reliably captured data for 92 individuals. The average age of participants was 32 years. They had on average 10 years of experience in sectors such as mechanical and aerospace engineering (product/system design, manufacturing, procurement, and contracting); information technology (software, services, and enterprise systems). The exercise contained multiple design rounds structured as treatment and control rounds, as shown in Figure 4.

Tutorial

At the start of the design session, the administrator simultaneously gave all participants a 10-minute tutorial on the design problem. The tutorial consisted of a prerecorded movie clip, with embedded presentation slides and a voice recording. The materials covered an example of a desalination plant, the long-term concession contract approach, design roles each party's objective functions, constraints, and the design variables that affected them. The presentation also included an overview of the DesalDesign software. Designers also received a one-page role sheet that summarized the information from the tutorial, in a way that emphasized and reinforced their role. Altogether the participants received the information using three media to support a number of different learning styles.

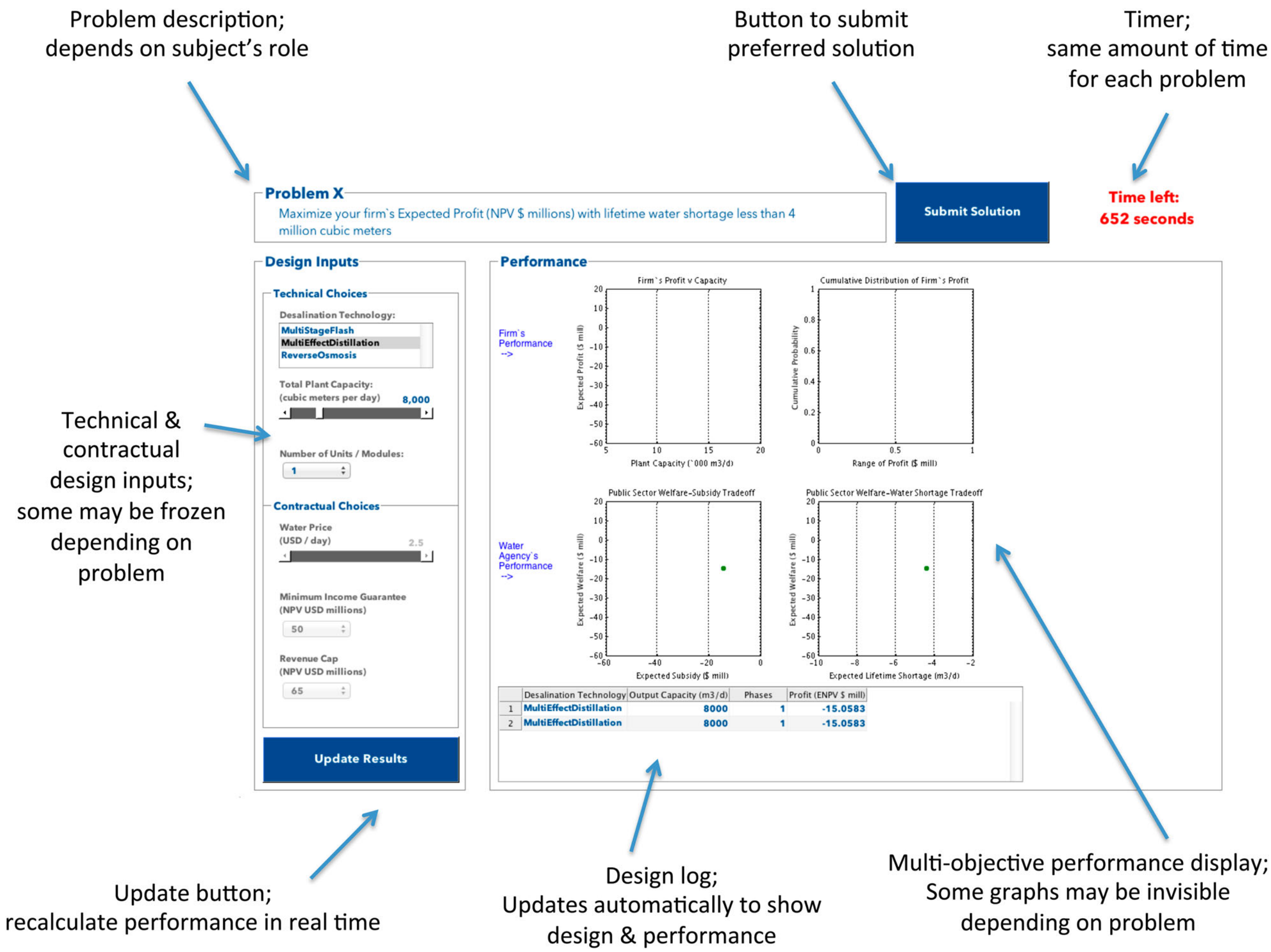

Figure 3. The user interface for the DesalDesign tradespace model.

Pre-exercise survey

The designers completed a pre-exercise survey immediately after the tutorial. Some questions addressed factual details covered in the tutorial and printed role sheet. These were designed to capture participant's understanding of the facts of the design problem. Participants were also asked to explicitly rank how well they thought they understood the design task and objectives. The first subset of questions had 'correct' responses with binary scoring (correct: 1, incorrect: 0) and total scores could range from 0 to 20. The rest of the questions were marked on 7-point Likert scales with a 1: 'Not at all', to a 4: 'Moderately', and 7: 'Extremely'. These scores were used to populate the measures of Objective Understanding (*ObjU*) and Subjective Understanding (*SubjU*) respectively (see Results section).

Treatments and controls

Prior to the exercise, designers were grouped in pairs through stratification and random selection, where each pair included one Water Authority role player and the other played the role of the Firm. Pairs were also randomly assigned to two groups called 'communication first' and 'information first'; their meanings are described further below. Pairs in both groups had to solve the same design problem four times. The design problem was identical in each round for both groups. This provided a natural control in the experiment since the structure of the task does not change.

For the first two problems, the control round and test of learning round, participants were told to design independently, without interacting with their pre-assigned counterparty in any way. In these first two rounds, designers only saw performance results that affected their performance objective. In other words, the Firm would see the trade-off of profits versus reliability, whereas the Water Authority would see the trade-off of contract payments with reliability. The first two problems helped to calibrate results and separate the effect of learning from the effects of negotiation in later rounds.

In Problem 3, two different treatments were applied, one to the 'communication first' group and the other to the 'information first' group:

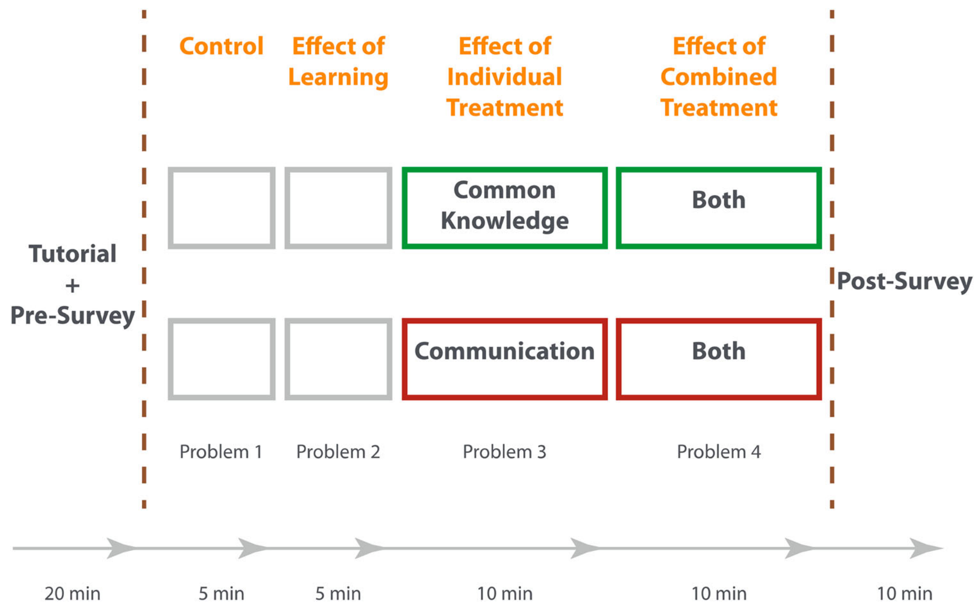

Figure 4. Structure of the design exercise to assess the effects of design negotiation on OV and SV outcomes.

(i) 'Communication' treatment: Under this treatment, participants were asked to begin dialogue with their pre-assigned counterparty to complete the design problem. Pairs of designers communicated using a private chat room created specifically for their dyad. The group that received Communication as the only individual treatment in Problem round 3 is labelled the 'communication first' treatment group.

(ii) 'Common Knowledge' treatment: In this treatment, designers saw information about both their own value outcomes and their counterparty's outcomes on their computer screen, without the ability to dialogue. Participants now had access to both their own results as well as the counterparty's results. The information asymmetry in performance between the two thus vanished. The group that received Common Knowledge as the treatment in Problem 3 is the 'information first' treatment group.

These two treatments were independent. A group of participant pairs could have Communication, Common Knowledge or both. All participants received both treatments in the final round, Problem 4. Thus both groups received both treatments, albeit in different orders (order switching). This allows us to isolate the effects of the two treatments in some parts of the analysis.

Post-exercise survey

Participants responded to a post-experiment survey after all four problems. Some questions elicited their perceived experience of the treatments. Specifically, participants stated whether completing the exercise resulted in an Improvement (*Im*) in their understanding. They also stated how much they attributed any improvement to the ability to communicate. The survey also asked about whether seeing additional information about the counter-party led to confusion, thereby detracting from their understanding.

Measuring Subjective Value

We measured SV with the Subjective Value Inventory (SVI), a measurement scale developed by Curhan *et al.* (2006). The SVI scale is an umbrella device and has four sub-dimensions or subscales, described below (Curhan *et al.*, 2010):

(1) Instrumental SV: whether designers perceived that the economic or OV outcomes in the design negotiations were balanced and legitimate based on their objective functions, using four questions about satisfaction, balance, loss, and legitimacy.

(2) Self SV: how competent designers felt during the session and whether they 'lost face'. The economic outcomes of some negotiations are not immediately revealed or clear, and negotiators resort to their own perceptions to find closure about the deal struck.

(3) Process SV: Perceptions of fairness in process, being heard or feeling listened to while expressing arguments, and perception of the counterpart adequately considering the self's viewpoint are captured by this sub-scale.

(4) Relationship SV: impressions about how positive the exchange between negotiators was, beliefs about whether trust was formed, and the laying down of a good foundation for future exchanges, if they were to transact again.

These four sub-dimensions of SV taken together comprise the global SVI measure. The post-survey at the end of the design exercise asked participants a series of questions along these lines adapted from the published SVI.

Results

The design exercise allowed us to identify how designers' SV from the exercise related to their degree of understanding in the design problem, and also to the OV outcomes. We needed to analyse both pre- and post-exercise data to establish these relationships. The supplemental material contains details on the results of the standard statistical procedures used to test sample bias, reliability scales, and preliminary relationships.

Designers' pre-exercise understanding

We measured understanding in two ways, using responses to the pre-exercise survey. The first, Objective Understanding (*ObjU*), measured designers' understanding of the facts and the design problem itself based on true/false and multiple choice questions on the information provided in the tutorial and role sheets. The second, Subjective Understanding (*SubjU*), records the designers' belief or perception about how well they understood the design problem and tasks at that moment in time. Two-sided differences-in-means tests (role, treatment group, gender, location, education) for each *ObjU* and *SubjU* did not show bias, or systematic differences for the sample of designers.

Participants' mood going into the design exercise may affect how they behave and perform. Mood (M) is a latent variable measuring instantaneous disposition, so the pre-exercise survey asked participants a number of indirect questions on motivation, confidence, and nervousness. Scores based on a final reliable Mood (M) scale ($\alpha = 0.65$) did not show bias in the sub-samples of designers.

We found that Subjective Understanding could be explained in relationship to Objective Understanding and Mood. In other words, *ObjU* and M predict the level of a designer's *SubjU* of the design problem prior to the exercise (adj. $R^2 = 0.39$; F statistic = 30.3; df 2, 89; $p < 0.01$). Subjective Understanding is twice as sensitive to designers Mood as their Objective Understanding, showing that an individual's emotional state can affect their perceived understanding of the design problem.

Designers' post-exercise understanding

The post-exercise survey asked designers a number of questions about whether their understanding improved after collaboration (Improvement, *Im*), whether communication with their collaborator increased their understanding (Communication factor, *Cm*), and whether seeing extra information about their collaborator's performance results confused them or detracted from understanding (Confusion factor, *Cf*). We link these three self-reported measures *Im*, *Cm*, and *Cf* to each other, and to Subjective Understanding, *SubjU*, discussed above. The supplemental materials contain some more details and the regression results.

The variable Improvement (*Im*) measured how a designer's understanding changed over the course of the collaboration exercise, after receiving the Communication and Common Knowledge treatments. In other words, *Im* is the designers' perceived change in *SubjU*. Participants' mental models and understanding will have evolved in both treatment groups as they coursed through the exercise, so we can expect both treatment groups to report an Improvement. A formal Analysis of Variance hypothesis test for whether one treatment group reported a systematically higher *Im* score showed that the *communication first* group (mean = 4.97, var = 1.92) reported higher *Im* with a lower spread than the *information first* group (mean = 4.51, var = 2.22), although the difference was not statistically significant ($p = 0.13$).

Designers reported how much they believed the improvement in understanding related to the ability to communicate (*Cm*) with their counterparty. Reported *Im* was found to correlate well with *Cm* ($r = 0.45$, $p < .001$; $\rho = 0.35$, $p < .001$). One hypothesis is that more of the *communication first* group's improvement in understanding came from the process of discussion with their collaborator. This group has a higher mean with much lower variance than the *information first* group. Specifically, the difference in means μ from a Welch test with unequal variance is 0.71 ($p < .05$, 95% CI: [0.02, 1.4]). Overall, these results imply that while both treatment groups reported Improvement (*Im*) in understanding, the *communication first* group attributed more of that improvement to communication.

Finally, the post-exercise survey also asked whether designers experienced confusion (*Cf*) when presented with the counterparty's performance results in the Common Knowledge condition. As expected, *Cf* is negatively correlated with *Im* ($r = -0.2$, $p = 0.06$; $\rho = -0.20$, $p = 0.05$), possibly detracting from Improvement (*Im*).

We tested a number of Ordinary Least-Squares models (see supplemental materials) linking these variables. Our interpretation of the best fit (Adj. $R^2 = 0.37$; *F* Statistic 10.13; df = 6, 85, $p < 0.01$) is that designers who reported an improvement in understanding by the end of the collaboration exercise attributed much of this improvement to the ability to engage in dialogue ('Communication' treatment) with each other. The additional information received (through the 'Common Knowledge') treatment had the potential to confuse participants. The degree of improvement in understanding (*Im*) also depended on the participant's own initial perception (*SubjU*) of how well they understood the problem at the start of the exercise. Even participants who thought they initially understood it well could find that their understanding improved further. If their initial perceived understanding was high, then communication still helped but to a lower degree than for the participant's with a low perceived understanding initially.

Designers' Subjective Value outcomes

Designers answered a series of questions in the post-exercise survey that provided the scores to populate the SVI. As discussed in the supplemental material, we obtained high α reliability estimates [0.7, 0.9] for both the Rapport and Global SV scores, so we could continue to use these scores to indicate SV in further analysis.

> H1 – Collaboration: How does SV relate to design collaboration mechanisms?

Most designers on the whole reported a large increase in SV after participating in the design exercise. The violin plots in Figure 5 shows the results by treatment group. The aggregate SVI scale for 'Increase in Subjective Value' is on the horizontal axis and ranges from 1: None to 7: Extreme. The red dashed line marks the scale mid-point. The ends of the coloured areas indicate the range of the observations for each group. The relative density of observations at each level of the scale is given by the width of the shaded area at each level of the scale.

We can see that most of the shaded area is well to the right of the scale mid-point of 'Moderate' increase in SV. SV outcomes by treatment group thus show that both groups (*communication first* and *information first*) experienced a large increase in SV, however, the two groups are not statistically different.

The conclusion from an analysis of SV by Role is similar. Participants in both the Water Authority's and the Firm's role reported that their SV increased after the

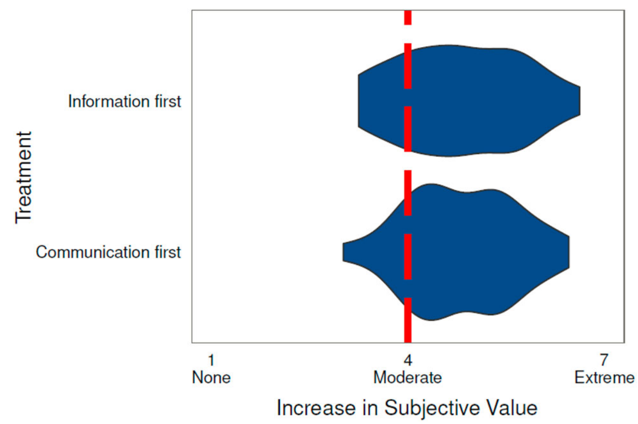

Figure 5. Overall SV results by treatment group across the sample of exercise participants with both the range and the density of observations shown.

design exercise, although the difference between the two groups is not statistically significant.

Looking at the results based on sample demographics, women designers appeared to experience higher SV along the Relationship sub-dimension, with a difference in means of slightly more than 0.7 points on the scale. Many women reported very high absolute increases of 6 or 7 on the Relationship sub-dimension. Tests of the dimensions of SV other than Relationship SV for correlation, means differences, and dependence on either experimental Role or Treatment condition did not produce statistically significant results.

> H2 – Understanding: How does SV relate to the designers' improvement in understanding?

Figure 6(a) shows how the aggregate SV scores changed with *Im*. The figure uses boxplots for SV to illustrate both the mean and the variation in outcomes, while controlling for *Im* on the horizontal axis. Except for the lowest level of *Im*, the distribution of aggregate SV score shifts upward on the SVI scale as *Im* increases. Even at the lowest *Im* ('no improvement' in understanding), a few participants reported a high increase in SV. Tests of correlation do in fact show that SV and *Im* are positively correlated ($r = 0.37$, $\rho = 0.41$, $p < 0.001$). We conclude that there is a positive relationship between how much participants felt their understanding improved after collaboration in the design exercise and the SV they ascribed to their experience.

> H3 – Agreement: How does SV relate to the OV outcomes from the exercise?

Here, we used the degree of agreement (*Ag*) in design choices, as a proxy for objective payoffs because, to balance value trade-offs between reliability of meeting demand, profit, and contract payments, the collaborators

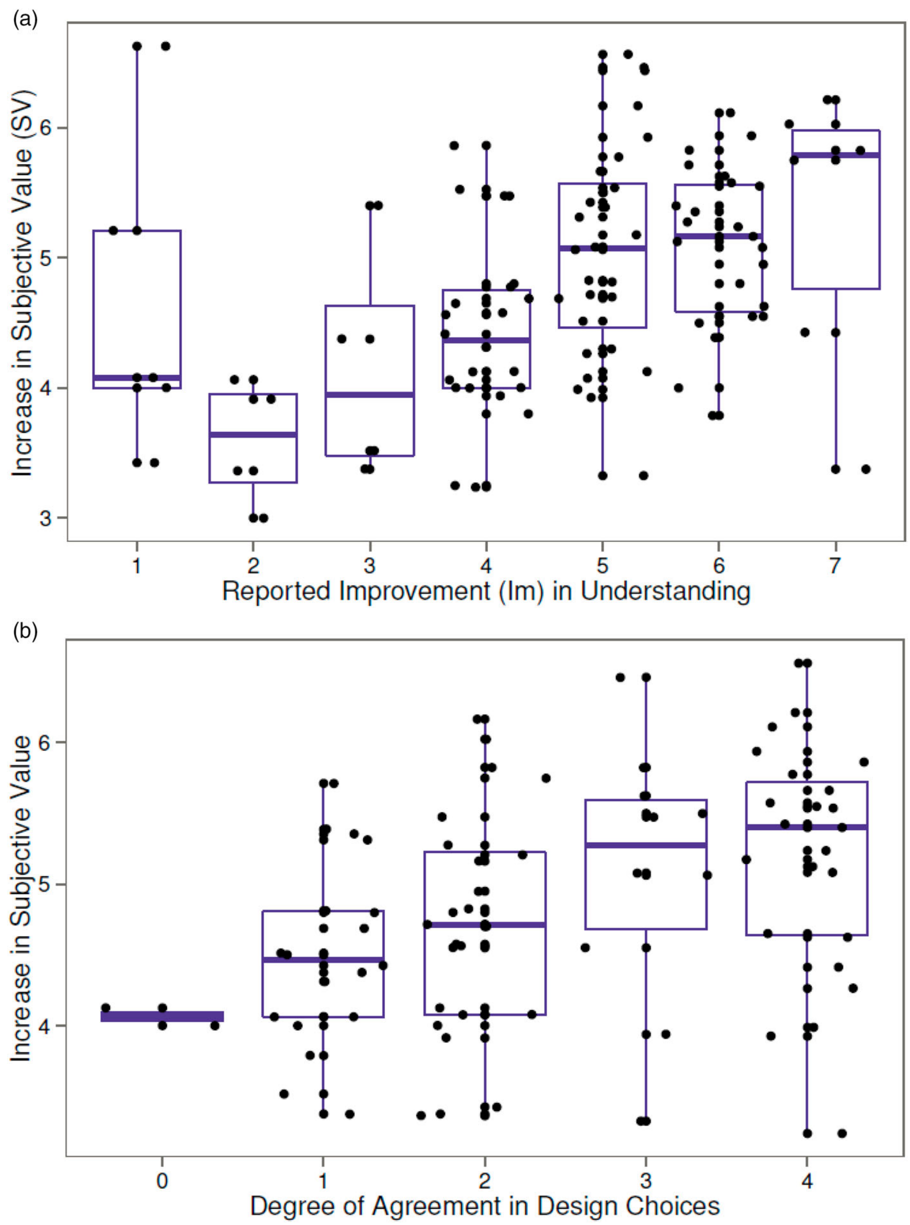

Figure 6. (a) Variation in the increase in SV through collaboration, controlling for the level of improvement in understanding and (b) variation in the increase in SV through collaboration, controlling for the degree of agreement in design choices (proxy for objective value outcomes).

had to agree on the independent dimensions of design. Designer's could agree on, i.e. pick identical design choices, for up to four design variables. Figure 6(b) therefore shows 0 – 'No Agreement' to 4 – 'Complete Agreement' in design choices. The distribution of aggregate SV scores suggests a positive relationship between SV and *Ag*, while controlling for the degree of agreement *Ag*. As the degree of agreement across designers increases, the mean level of increase in SV rises. However, the variation in SV scores also increases. It becomes clear that designers who did not agree on designs reported low increases in SV as a result of collaboration. There are also many participants with both high Ag and SV scores. The resulting correlation between SV and Ag is significantly positive ($r = 0.36$, $\rho = 0.36$, $p = 0.001$).

Many participants who did agree on a high number of design dimensions experienced low SV change after the exercise. This supports the idea that negotiated agreements do not always result in high SV outcomes, for example, when negotiators feel that they are forced to agree because of some external enforcing mechanism. Since the design exercise had no enforcing mechanism, the low SV scores are likely due to the negotiating dynamics in collaborating pairs interacting with their attributes (Subjective Understanding, Mood, etc.)

In sum, our findings show that negotiating designers on the whole experienced a large increase in SV, their psychosocial outcomes, from the collaborative mechanisms in design. The large increase was observed across both treatment groups, both communication and information sharing, as well as across the design roles. Women in particular ascribed higher increases in SV to its relationship aspects, compared to men. Designers who believed that their understanding of the design issues improved significantly through collaboration also exhibited high increases in SV. In a similar manner, if collaborators agreed on design choices, they tended to report higher SV increases on average.

Discussion

A designer's degree of understanding can help or hinder the objective of approaching agreement on design choices. This study demonstrated that a participant's Subjective Understanding, or their initial mental model, is predicted by not only their understanding of the facts and structure of the problem, but also by their disposition or mood at the time of the exercise. Further, participants who reported an improvement in understanding (i.e. a change in their mental model) after problem-solving in the design exercise attributed much of this improvement to the ability to communicate with each other. The additional information received through common knowledge had the potential to confuse participants. The degree of improvement in understanding also depended on the participant's own initial perception of how well they understood the problem at the start of the exercise. Even participants who thought they initially understood it well could find that their understanding improved further. If their initial perceived understanding was high, then communication still helped but to a lower degree than for the participant's with a low perceived understanding initially.

SV represents the psychosocial type of outcomes experienced in negotiations. This construct is also based on perceptions and mental models and has the potential to influence the quality of future design sessions with the same partners, and even the conclusions a participant reaches about the results after a single design session. Designers on the whole experienced a large increase in SV from negotiating agreement over designs. The results also show that many collaborators who demonstrated high agreement often reported low increases in SV. Even though there is agreement, the manner in which this agreement is obtained can detract from collaborators psychosocial experience. For example, if agreement is forced or manipulated, the negotiating collaborators may be more likely find the experience negative. In this exercise, however, there were no forcing mechanisms or requirements for designers to agree with each other. The observed variation in the results thus points to the very realistic possibility of negative experience after forced agreement. It is therefore important to consider not only the techno-economic or OV outcomes of negotiated collaboration, but also the SV outcomes in design negotiations.

Conclusion

This research addresses the issue that designer understanding and psychosocial effects on designers as *dependent* or outcome variables are often left untreated in project design and negotiation studies because they are transient and difficult to measure. Leaving these out leads to an incomplete picture of what transpires in project negotiations, and implications for the rest of the project. Curhan *et al.* (2006) recently formalized the construct of SV to measure the psychosocial outcomes of negotiations, providing a robust theoretical framework for assessing these effects in project design negotiations. Measuring and linking these transient outcomes with technical design choices provide a more holistic view of the nature of negotiated design in projects.

We are also able to round out our understanding of the behavior and experience of *individual actors in projects*, adding to the insights of game theory, contracting and project organization from observing the project at a distance. A more complete description of the 'lived' subjective experience of individual project actors can help us test future prescriptions about how to structure project design and negotiation processes to so that individual designers can effectively balance trade-offs to meet multiple objectives, while maintaining trust, credibility, and rapport. While particularly relevant to infrastructure P3 projects which commonly involve techno-economic design negotiation, links among participant understanding, psychosocial effects, and agreement in choices extend to other negotiation settings that involve non-zero sum bargaining.

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