HARVARD | BUSINESS | SCHOOL

# The Role of Constraints in Creative Problem-Solving: Field Experimental Evidence from a Community Crowdsourcing Program in a Consumer Electronics Company

Daniel Ehls
Karim R. Lakhani
Jacqueline N. Lane

**Working Paper 21-068**

# The Role of Constraints in Creative Problem-Solving: Field Experimental Evidence from a Community Crowdsourcing Program in a Consumer Electronics Company

Daniel Ehls
Helmut Schmidt University

Karim R. Lakhani
Harvard Business School

Jacqueline N. Lane
Harvard Business School

**Working Paper 21-068**



Funding for this research was provided in part by Harvard Business School.

# The Role of Constraints in Creative Problem-Solving: Field Experimental Evidence from a Community Crowdsourcing Program in a Consumer Electronics Company

Daniel Ehls,[1,3] Karim R. Lakhani,[2,3] and Jacqueline N. Lane[2,3]

[1]Helmut Schmidt University, Hamburg Germany
[2]Harvard Business School, Boston MA
[3]Laboratory for Innovation Science at Harvard

## Abstract

The role of constraints in the problem solving process has been a central line of inquiry in the creativity and innovation literature with ongoing debates of whether constraints imposed on creative problem solvers diminish or enhance their efforts and outputs. We investigate this question by designing and executing a field experiment in collaboration with a world leading company in consumer electronics seeking creative solutions through a community crowdsourcing program to improve the wearing comfort of their popular headphones. We mobilized 1,833 problem solvers, 331 ideas and 435 community evaluators to rate the quality of the solutions, for a total of 2,473 evaluator-solution pairs. To make experimental comparisons, we exogenously varied the number of constraints faced by the community problem solvers to determine how exposures to constraints affected the number and quality of solutions. We find causal evidence that moderate levels of constraints increase both solution quantity and quality. Compared to problems framed with no constraints, having some constraints causally increases a solvers' likelihood of proposing a solution by 6% or 1.5 times. Turning to solution quality, we find that while constraints decrease the average novelty of solutions, they have no effect on the most novel and useful solutions. Lastly, we observe an inverse curvilinear relationship between the number of constraints and the most creative solutions, where problems with some constraints increase the likelihood of coming up with one of the most creative solutions by 3-4% compared to problems with no constraints. We discuss the implications of our findings to the creativity and problem-solving literatures.

Acknowledgements: We would like to thank Laboratory for Innovation Science at Harvard research scientists Andrea Blasco, Michael Menietti, and Rinat Sergeev for their advice and counsel during the design phase of the experiment, Michael Fretschner and Christian Lüthje from Hamburg University of Technology for providing helpful comments and suggestions during the initial stage of this research project, Erik Derma and Julian Kühn for help with data collection, and the Company for their partnership and access to their community.

## 1. Introduction

*"When people think about creativity, they think about artistic work – unbridled, unguided effort that leads to beautiful effect. But if you look deeper, you'll find that some of the most inspiring art forms, such as haikus, sonatas, and religious paintings, are fraught with constraints. They are beautiful because creativity triumphed over the 'rules.' Constraints shape and focus problems and provide clear challenges to overcome. Creativity thrives best when constrained."* (Marissa Mayer 2006, as quoted in Bloomberg Businessweek, 2006).

Creative problem-solving, as a focal unit of analysis, has emerged as a central issue in the knowledge-based theory of the firm (Nickerson & Zenger, 2004; Nonaka & Von Krogh, 2009). Success at value creation inside of companies is a function of how effectively managers identify, select and define insightful problems that need to be solved (Getzels & Csikszentmihalyi, 1975; Isen, Daubman, & Nowicki, 1987; Simon & Newell, 1971; Weisberg, 2006), as well as their ability to marshal the internal and external resources available to the firm to generate valuable solutions (Baer, Dirks, & Nickerson, 2013; Felin & Zenger, 2014; Leiblein & Macher, 2009; Macher & Boerner, 2012).

Despite the importance of problem formulation in determining the number and quality of alternative solutions produced during problem solving (Baer et al., 2013; Rietzschel, Nijstad, & Stroebe, 2014), most extant research has focused on the process of generating and selecting creative solutions that are novel and useful in a domain (Amabile, 1996; Boudreau, Guinan, Lakhani, & Riedl, 2016; Piezunka & Dahlander, 2015; Shalley, 1991; Shalley, Zhou, & Oldham, 2004; Zhou, Wang, Bavato, Tasselli, & Wu, 2019) rather than the process of formulating problems *before* solving them (Baer et al., 2013; Csikszentmihalyi & Getzels, 1971; Cummiskey & Baer, 2018). Hence, there exists a lack of understanding of the microfoundations of this essential activity (Felin & Zenger, 2014).

One potential reason for this lack of understanding may be attributed to the fact that a broadly shared view among many creativity scholars is that the ideal creative problem solving process is one that is unstructured, open and free of external limitations (Amabile, 1996; Amabile, Conti, Coon, Lazenby, & Herron, 1996; Shalley, 1991). Similarly, there is an emerging line of problem-solving research that proposes that in certain cases, problem formulation may not be required when solvers focus on a need-solution pair. When a need and a solution are discovered together, then problem formulation only occurs after the discovery of the need-solution pair, if at all (Von Hippel & Von Krogh, 2016). That being said, a counter viewpoint surfacing in recent years, suggests that creative problem solving is not a random process (Harvey, 2014) but rather, one that may generate more productive searches and higher quality solutions when problem constraints lead solvers to search for solutions in certain problem spaces over others (Acar, Tarakci, & van Knippenberg, 2019; Acar & van den Ende, 2016; Cromwell, Amabile, & Harvey, 2018; Rosso, 2014). Problem constraints include any externally imposed factor – such as rules and regulations, deadlines, norms, resource scarcity, requirements, restrictions on choice, and boundaries that *limit* the number of possible solutions available for solving a problem and *direct* the search for new ideas in some domains (Acar et al., 2019; Caniëls & Rietzschel, 2015; Cummiskey & Baer, 2018; Stokes, 2001, 2005). A potential reason why constraints may stimulate rather than hinder creativity is their ability to make a difficult problem or task more manageable (Caniëls & Rietzschel, 2015; Rietzschel et al., 2014). People may become overwhelmed when given too much freedom, leading to a “paradox of choice” (Schwartz, 2004), where extensive choice and resources can be demotivating (Iyengar & Lepper, 2000), and detrimental to creativity (Chua & Iyengar, 2008). Also, because attention and time are limited (Csikszentmihalyi, 1997; Ocasio, 1997; Simon & Newell, 1971), having an abundance of choice may unintentionally undermine people’s abilities to engage in deliberate and deep cognitive processing of information (Piezunka & Dahlander, 2015; Rhee & Leonardi, 2018).

To reconcile these opposing views of how problem constraints affect creativity, some scholars have proposed that an inverted U-shaped or curvilinear relationship exists between problem constraints and the creative problem solving process – positing that a moderate level of constraints enhances creativity, but excessive constraints can ultimately undermine it (Acar et al., 2019; Joyce, 2009; Rosso, 2014). Despite the presumably intuitive nature of this relationship, there has been relatively little research to date that has examined when and why a curvilinear relationship between problem constraints and creativity is more or less likely to be exhibited. Prior work has noted that creative solutions are a function of both the quantity of solutions and the quality of those ideas, where productivity or the number of solutions produced during idea generation is not always a sufficient condition for better solutions (Rietzschel, Nijstad, & Stroebe, 2006, 2007). Building on this literature, our present research considers how problem constraints may affect both the number and quality of the solutions generated from creative problem solving. To further examine the nature of the relationship between constraints and idea quality within the context of creativity, we further differentiate quality into its components of novelty and usefulness (Amabile, 1996; Diehl & Stroebe, 1987; Shelley, 1991). In conceptualizing creativity this way, with multiple stages and components, we address the possibility that problem constraints may have distinct, and potentially contrasting effects on different outcomes of idea generation, and different components of the creative process.

To draw causal inferences, we designed and executed a field experiment in collaboration with a world leading company for consumer electronics seeking creative designs to improve the wearing comfort of their popular headphones through their ongoing community crowdsourcing efforts. The initial call went out to 32,476 subscribers of the company's newsletter, which attracted 1,833 problem solvers and 331 ideas. A second, follow up call then recruited 435 community evaluators to rate the quality of the ideas for a total of 2,473 evaluator-solution pairs.

Our results indicate that imposing some problem constraints benefits both the generation and selection of the high quality ideas during the creative problem solving process. First, we find that intermediate levels of constraints can increase the quantity of solutions: having some constraints causally increases the likelihood that a solver submits a solution by 6 percentage points (pp) or 1.5 times more than problems with no constraints. Therefore, constraints benefit idea quantity up until a certain threshold, after which there are decreasing returns to additional constraints. Second, examining the novelty and usefulness of proposed solutions, we show that while an increase in problem constraints decreases the average solution novelty, constraints do not change the distribution of the most novel ideas. We also find no significant relationship between the number of problem constraints and the usefulness of a solution. This suggests that adding problem constraints can increase idea quantity without dampening the novelty or usefulness of the most unique ideas. Third, we find evidence of an inverted U-shaped relationship between the number of problem constraints and the most creative solutions, with some constraints increasing the likelihood of coming up with one of the most creative solutions by 3-4pp compared to problems with no constraints. Overall, our results indicate that some constraints are beneficial to both the quantity and quality of solutions. Some constraints benefit the creative problem solving process, but too many constraints dampen it.

The remainder of the paper is organized as follows. Section 2 reviews past literature and motivates possible links between problem constraints and creativity. Section 3 describes the research design. Section 4 presents the main results, and section 5 concludes with a discussion of the main findings and their implications.

## 2. Theory and Hypotheses

### 2.1. Creativity as Problem Formulation and Problem Solving

Creativity is reflected through the generation of novel and useful solutions (Acar et al., 2019; Amabile, 1996; Runco, 1994; Shalley, 1991). Ideas are novel if they are unique relative to other ideas in the market, and are useful if they have potential value to an organization (Acar et al., 2019; Shalley et al., 2004). Much research has suggested that creative problem solving is a special representation or form of problem formulation and problem solving (Baer et al., 2013; Csikszentmihalyi & Getzels, 1971; Getzels, 1975; Isen et al., 1987; Runco, 1994; Simon, 1983) that involves the generation and selection of discretionary actions to arrive at a goal state (Baer et al., 2013). This is consistent with the psychological view that a problem occurs when an individual or organization has a "goal to achieve and does not know how to achieve it" (Baron, 2000, pg. 49). When people generate a new idea that satisfies their objectives (Newell & Simon, 1972), they have chosen a possible path from several alternative paths, and have constructed and implemented a course of action to achieve an end goal state (Amabile, 1996; Runco, 1994).

Problem formulation refers to the process of discovering, identifying and defining a problem before it is solved (Amabile, 2018; Dillon, 1982; Getzels, 1975; Getzels & Csikszentmihalyi, 1975). Although a large body of literature has focused on solving a problem after it has been formulated, the process of formulating a problem can be more essential than its solution (Baer et al., 2013; Getzels & Csikszentmihalyi, 1975). As Einstein and Infeld (1938) remarked: "To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science (p. 92)".

Problem constraints are any externally imposed factor—such as rules and regulations, deadlines, norms, resource scarcity, requirements, restrictions on choice, and boundaries that *limit* the number of possible solutions available for solving a problem and *direct* the search for new ideas to solve problems (Acar et al., 2019; Cummiskey & Baer, 2018; Rosso, 2014; Stokes, 2001, 2005). Constraints offer a theoretical yet practical lens for conceptualizing how problem formulation relates to the creative problem solving process. When viewed in this light, problems lie on a continuum depending on the degree that it has been formulated before a solver begins the creative process, ranging from open to closed (Getzels & Csikszentmihalyi, 1975; Unsworth, 2001). A closed problem is one where the problem is clearly given at the start, and where the method and solution are already known. The problem solver only needs to adopt the "correct" procedural steps to arrive at a solution. An algebra problem is an example of a closed problem because students are given a set of equations and asked to solve the problem using a set of well-known principles, heuristics (or algorithms) and rules to arrive at a known solution (Getzels, 1975; Simon, 1983). At the other end of the continuum is open problems, where the problem has not yet been formulated and the solver is required to find or "discover" the problem and develop an appropriate method for reaching an unknown solution (Csikszentmihalyi & Getzels, 1971; Getzels & Csikszentmihalyi, 1975). A blank page or canvas are examples of open problems, where the problem needs to be "discovered" before a writer or artist can begin solving it (Dewey, 1997; Dillon, 1982; Joyce, 2009).

The number of constraints imposed on a problem introduces boundaries limiting the requirements, needs, and objectives that define the goal state and direct how people search for potential solutions (Reitman, 1965; Stokes, 2001, 2005). When problem constraints are low – i.e., open problems, it means that solvers are working within a larger, and broader problem domain and have fewer requirements to satisfy at the end goal state. In contrast, when problem constraints are high – i.e., closed problems, it means that the problem domain is narrower and there are more requirements or conditions that need to be met before an idea can be a solution (Cummiskey & Baer, 2018; Harvey, 2014; Unsworth, 2001). Accordingly, fewer ideas are capable of satisfying the end goal state when there are more constraints on the problem space.

In the next sections, we theorize the effects of constraints on the quantity and quality of generated ideas, focusing on the novelty, usefulness and ultimately the creativity of these ideas.

### 2.2. Problem Constraints and Solution Quantity

Problem constraints limit the degree of choice and freedom available for idea generation and direct search behavior to some parts of the problem space over others (Csikszentmihalyi & Getzels, 1971; Stokes, 2001, 2005). Although scholars of creativity and innovation have long viewed constraints as being detrimental to creativity (Amabile, 1983; Amabile et al., 1996; Cyert & March, 1963; Shalley, 1991), there is a growing perspective that constraints may facilitate idea generation because they reduce the complexity and the information processing demands of the task at hand (Hirst, Van Knippenberg, & Zhou, 2009; Simon, 1978). Research on decision-making and judgment indicates that extensive choice and autonomy can be difficult to manage (Kahneman, 2011), leading people to make suboptimal decisions, such as considering fewer choices, choosing the default option or opting out altogether (Iyengar & Lepper, 2000). The "paradox of choice" (Schwartz, 2004) suggests that people are not able to encode, process and integrate information effectively when they are presented with a large number of possible options, relying instead on simple heuristics (Gigerenzer & Gaissmaier, 2011; Iyengar & Lepper, 2000). When people are asked to solve open, minimally constrained problems, the freedom to choose among many alternative paths may result in choice overload, which can inhibit them from coming up with potential ideas or solutions, and opt out of solving a problem altogether.

Another reason why open problems may inhibit idea generation is due to the limits of people's attentional resources. Individuals have a finite amount of attention to allocate and can only pay attention to a subset of the information that they encounter (Cyert & March, 1963; Ocasio, 1997; Piezunka & Dahlander, 2015). Attention allocation involves the focusing of time and effort on a stimulus (Haas, Criscuolo, & George, 2015; Kahneman, 1973). Kahneman (1973)'s theory of attention suggests that there are generally two primary strategies that people use to allocate their attention. People can either adopt *divided* attention, where they symmetrize their attentional resources across information inputs or stimuli, or *focused* attention, which involves deliberate cognitive processing of information coming from a specific stimulus that originated from a particular source or has some feature or characteristic (Kahneman, 1973). The degree to which a problem is open (few constraints) versus closed (many constraints) may affect how people allocate their attention when coming up with ideas. When the problem has few constraints, people may be more likely to allocate their attention along many potential directions while searching for a solution. However, a clear trade-off is that they are not able to focus their attention and cognitive effort on any one specific direction, thereby limiting their ability to converge on a potential solution or idea. In contrast, problems with some degree of constraints may enable people to think more deeply within a single category or path, which can facilitate idea convergence (Rietzschel et al., 2006). For example, Haas, Criscuolo and George (2015) found that potential problem solvers were more likely to contribute knowledge to an online discussion forum when the problem had some constraints (e.g., narrower, less novel and shorter problem description) because they demanded less cognitive load (Haas et al., 2015), potentially enabling the solver to focus rather than divide their attention across categories or domains.

This suggests that adding some constraints to problems may be beneficial to solution generation, compared to open problems that may offer too much choice and divide a solver's attentional resources. That said, problems with an excessive number of constraints may inadvertently diminish a solver's intrinsic motivation to engage in idea generation (Deci & Ryan, 2010), which is considered to be one of the most powerful influences on creativity (Amabile, 1996; Amabile et al., 1996; Shalley, 1991, 1995; Zhang & Bartol, 2010). The problem becomes less enjoyable to solve, requiring few creative inputs, thereby reducing an individual's propensity to devote attention to it and persist in solving it (Amabile, 1996; Grant & Berry, 2011).

In summary, an open problem that has few constraints can fail to generate ideas from a potential problem solver because complete freedom may offer too much choice or inhibit focusing of attention, while a closed problem with many constraints can also hinder idea generation because it reduces the intrinsic enjoyment of the creative process. Taken together, these arguments suggest that there will be a curvilinear relationship between the number of constraints imposed on a problem and the propensity that a problem solver will generate a new idea or solution to that problem, such that the propensity to submit an idea will be increasing in the number of problem constraints, but only up to a point, after which further constraints will have negative effects on the likelihood of idea generation. Hence, we hypothesize:

*Hypothesis 1. The likelihood that a problem solver proposes an solution to a focal problem is curvilinearly related to the number of constraints imposed on the problem, in an inverse U-shape.*

### 2.3. Problem Constraints and Solution Novelty

Although moderate levels of constraint may improve the problem solver's propensity to come up with solutions, the quantity of solutions generated does not necessarily correspond to the quality of the solutions selected during evaluation (Rietzschel et al., 2014), as one only needs a few high quality ideas to be selected for further development (Girotra, Terwiesch, & Ulrich, 2010; Rietzschel et al., 2006). Within organizations, idea quality generally refers to the extent that the solution is creative – being both novel compared to existing ideas in the market, and potentially useful to an organization (Acar et al., 2019; Shalley et al., 2004). In this section, we theorize the role of problem constraints on the solution's novelty, and hypothesize that constraints will have a negative impact on a solution's novelty for three reasons.

First, the role of constraints is to limit or preclude search behavior in some parts of a problem space while promoting search in different parts (Reitman, 1965). Put differently, constraints may reduce search scope while increasing search depth, which may limit exploratory behaviors and reinforce exploitation behaviors, i.e., paradigmatic rigidity (Chai, 2017; March, 1991). In particular, by limiting search behavior, constraints promote the use of the same knowledge elements via local search strategies for new ideas in conceptual spaces that are likely to be familiar or related to the problem at hand (Katila & Ahuja, 2002); examples of such strategies may include prior solutions and existing organizational routines (March, 1991).

Second, by directing search along some parts of the solution space, constraints limit the amount of choice available for problem solving (March, 1991), which may reduce a solver's ability to find and integrate different knowledge elements in overlooked parts of the problem space (Laursen & Salter, 2006). In their study of the problem formulation stage and creative activity, Csikszentmihalyi and Getzels (1971) found a positive relationship between the amount of "discovery-oriented" behavior (i.e., behaviors used to identify, structure, and approach a solution) and the novelty of the creative product. By adding constraints, the problem seeker enacts boundaries on the methods or approaches that are deemed appropriate for reaching a solution; accordingly, the problem becomes more closed. These constraints may filter out alternative perspectives from marginal individuals (Jeppesen & Lakhani, 2010) and possible solutions that capture distant knowledge (Piezunka & Dahlander, 2015). Moreover, given that novel solutions are often formed from the reuse, integration and recombination of existing ideas in novel ways or by incorporating new ideas with more established ones (Fleming, Mingo, & Chen, 2007; Katila & Ahuja, 2002), constraints may reduce a solution's novelty by precluding a solver from searching in distant and unfamiliar search terrains (Li, Maggitti, Smith, Tesluk, & Katila, 2013) and making atypical associations between different knowledge domains (Schilling & Green, 2011).

Third, constraints reduce the variability of proposed solutions by imposing boundaries demarcating what is possible from what is out of scope. When problems add many constraints and become relatively closed, both the method for solving the problem and the solution are already known, creating little variation, imagination, or unpredictability in the range of relevant outcomes (Stokes, 2001). Moreover, ideas that are similar in content and approach are likely to be of similar quality or novelty (Girotra et al., 2010). Therefore, there is a smaller chance for outlier ideas that fall outside the predictable range of expected solutions. Based on these reasons, we predict:

*Hypothesis 2 (H2). The likelihood that a problem solver proposes a novel solution is negatively related to the number of constraints imposed on the problem.*

### 2.4. Problem Constraints and Solution Usefulness

Although one aspect of idea quality is the novelty of the solution, the other component of idea quality is its usefulness (Shalley et al., 2004). The ability to come up with useful ideas is particularly critical when firms need to focus on more immediate and certain outcomes, rather than distal yet variable outcomes (He & Wong, 2004) that are often associated with unproven and novel but also high risk technologies and products (Sine, Haveman, & Tolbert, 2005).

In technical domains, a solution's usefulness often refers to the firm's internal assessment of whether a solution can be implemented efficiently and reliably using existing technological capabilities, i.e., the extent to which a solution is feasible (Ulrich, 2011). If the search for novel solutions favor exploratory behaviors, associated with increased search scope, risk taking and experimentation, then the search for useful solutions is likely to benefit from exploitation behaviors characterized by refinement, implementation, selection and efficiency ((He & Wong, 2004; March, 1991). Prior work suggests that the structures, processes and behaviors needed to generate novel solutions are likely to differ from those needed for useful solutions (Benner & Tushman, 2002; Rosenkopf & Nerkar, 2001). That is, the search for novel versus useful solutions are not necessarily complementary in nature. Whereas some research has suggested that these objectives are orthogonally related (Gupta, Smith, & Shalley, 2006), other research has also suggested that these behaviors represent trade-offs that are negatively related to each other (Poetz & Schreier, 2012). If problem constraints reduce the amount of exploratory behaviors needed for novelty-seeking solutions, then adding constraints may effectively promote exploitation behaviors that make better use of a firm's existing knowledge and capabilities. Such limitations and directions are likely to promote useful solutions that are both technically doable and economically viable (Gupta et al., 2006; March, 1991; Sine et al., 2005). This may be particularly effective in directing search behaviors among community end-users, who are typically unaware of the internal technical and economic capabilities of the firm and known only by its deep domain experts (Amabile, 1998; Ulrich, 2011). Hence, we predict the following:

*Hypothesis 3. The likelihood that a problem solver proposes a useful solution is positively related to the number of constraints imposed on the problem.*

### 2.5. Problem Constraints and Solution Creativity

Given that creativity requires a balance of novelty and usefulness (Amabile et al., 1996; Shalley et al., 2004; Weisberg, 2006), this suggests that solvers are more likely to come up with higher quality ideas, i.e., more creative solutions when problems have some constraints that limit and direct search behavior in certain domains over others (Acar et al., 2019; Acar & van den Ende, 2016; Rietzschel et al., 2014). Whereas solution novelty requires uniqueness, creative solutions need to satisfy an additional condition of also being useful or relevant (Cummiskey & Baer, 2018; Jeppesen & Lakhani, 2010). Firms often face numerous constraints, such as time, money, resources, and assets, which are inevitably a part of all creative problem solving activities in organizations (Acar et al., 2019; Shalley et al., 2004). Although innovation scholars have argued that resource abundance or "slack" is a necessary condition to encourage experimentation and risky projects (Cyert & March, 1963; Levinthal & March, 1981), another view suggests that constraints may spur creativity by preventing problem solvers from falling back on the path of least resistance (POLR). The POLR suggests that people are more likely to generate uncreative ideas when offered complete freedom to ideate (Bayus, 2013; Csikszentmihalyi, 1997; Ward, 1994; Ward, Smith, & Finke, 1999). In a qualitative study of Coloplast, a major international manufacturer of medical equipment, Onarheim (2012) found that creativity and constraints complement one another in engineering design, with constraints "guiding and limiting the creative process" and demonstrating that problem solvers can maintain an optimal combination or "sweet spot" of constraints (e.g., by adding, removing and altering constraints) to enhance creativity (Onarheim, 2012).

These arguments suggest that problems with moderate levels of constraints are more likely to lead to creative solutions, compared to open or closed problems with few or many constraints. This is due to the fact that creativity requires a balance of novelty and usefulness. Accordingly, we hypothesize that there is a curvilinear relationship between the number of constraints imposed on a problem and the creativity of the idea or solution, such that a larger number of constraints will have a positive effect on the likelihood of generating a creative solution, up until a threshold, after which any additional increase will have a negative effect on the likelihood of coming up with a creative idea.

*Hypothesis 4 (H4). The likelihood that a problem solver proposes a creative solution is curvilinearly related to the number of constraints imposed on the problem, in an inverse U-shape.*

## 3. Research Design

Empirically testing the above hypotheses for causal inferences imposes several significant challenges. The first challenge is to ensure that constraints need to be added to the same underlying innovation problem. The second challenge is to ensure that multiple problem solvers, i.e. sufficient numbers for statistical inference, are available to work on creating the solution. The third challenge is to ensure randomization is possible so that problem solvers do not choose to solve the problems they want but are instead randomly assigned to the different constraint treatment conditions and that the problem solvers are not aware of the presence of other treatments. The fourth challenge is to ensure that evaluation of the creative solutions is not tainted by idiosyncratic tastes of the judges and that multiple evaluators rate multiple solutions. These challenges impose significant constraints on our research design. It may be very difficult to convince a company that it should dedicate hundreds of engineers and staff to both work on the same problem and to ensure randomization and isolation of treatments and participants in an industrial research laboratory. Our solution to this problem was to rely on a company's extended open innovation ecosystem and execute the experiment through a crowdsourcing contest within its expert user community. Relying on the external and global user community enables us to overcome the causal inference challenges by executing the experiment in an online setting. In this section, we describe the key aspects of the research design, the subjects, and the treatment conditions. We then conclude the section by describing the main variables and the empirical estimation strategy.

### 3.1. Setting

We collaborated with a world leading company in consumer electronics to examine the effects of constraints on the creativity process, drawing on a pool of crowdsourced community members for idea generation and evaluation. Among other music products, the company produces industry-leading headphones. As indicated by reviews from consumer magazines, and confirmed by interviews with company executives, we identified three key criteria for purchasing headphones: sound, design, and wearing comfort. Our experiment focused on crowdsourcing ideas to improve the wearing comfort of the company's headphones. The company uses email newsletters every 5-6 weeks to inform expert consumers about its music equipment that anyone can sign up to receive. Within the regular newsletter edition of December 2015 in Germany and Austria, we inserted a link calling all subscribers to "participate in a lottery and idea search initiative for the music equipment of tomorrow". After clicking on the link, participants were directed to a welcome page in the design of the company newsletter, with the authors' university logos embedded at the bottom that included a statement asking whether they would be willing to participate in the idea search and a description of the prizes for the lottery (i.e., an Ivy League University t-shirt, a pair of Company headphones). To be eligible for a prize, individuals were required to participate in the problem solving activity of generating solutions to a future headphone design task.

### 3.2. Solver Participants

We sent the invitation to participate in the survey to 32,476 subscribers of the company's newsletter, which generated 2,877 (or 9.54%) unique clicks of the survey link. A total of 1,833 participants were exposed to the randomized experimental task, of which 470 completed the task, generating a total of 331 unique ideas.[1] In the analysis that follows, we focus on the 1,833 participants that started the task and the 331 unique solutions generated in response to the call for ideas. In interviews conducted with company executives, we verified that the click through rates and the demographic characteristics of the survey participants were similar to those of company's regular newsletter subscribers.[2]

### 3.3. Solver Procedures and Treatments

After clicking on the survey link , potential solvers were asked to answer a set of questions about their knowledge about headphones, their information breadth, which referred to the number of sources they use to keep up regularly with the latest trends and technologies in the music industry, their motivation for participating in the ideation task, and their demographic characteristics. After completing these background questions, participants were exposed to a problem statement.

Figure 1 (left) illustrates the base problem statement shown to all participants (control and treatment conditions) and the text blocks (Figure 1 right) that were added to the treatment

[1] We excluded double entries, blank entries, and any non-idea/comments (e.g., "I do not have an idea", "I am not willing to give my idea for free". After data cleaning, each solver proposed one unique solution.
[2] Statistics are not reported for Company confidentiality reasons.

groups. We exogenously manipulated the number of constraints imposed on the problem statement using different text blocks. The participants in the treatment groups were randomly assigned to either a "low" (1 constraint), "moderate" (2 constraints) or "high" (3 constraints) condition. Figure 1 provides a description of the three constraints. The first constraint, *providing directions*, directed the solvers' search behaviors by including additional details describing wearing comfort, and included various sample use cases to direct the solvers' attention to particular parts of the solution space, but not prime them to a particular use case. The second constraint, *limiting solutions*, provided explicit instructions to generate ideas that were feasible and technically doable, thereby emphasizing the usability of the solutions. For both the *providing directions* and *limiting solutions* constraints, solvers either saw the stimuli or not.

The third and final constraint, *community evaluation*, emphasized whether the proposed ideas/solution would be evaluated by community members (i.e., non-experts) or firm experts. Prior creativity research has suggested that creativity can be influenced by whether an individual expects a judgmental evaluation that critically assesses the creativity of his or her work against a standard (Shalley et al., 2004). Given that our participant base of end-users are more likely to focus on developing solutions for themselves and other users, we reasoned that they are more likely to identify with the community of other end users, and perceive that evaluations from the community would be more judgmental (i.e., reputation enhancing or diminishing) compared to private evaluations from firm experts (Chatterji & Fabrizio, 2014; Shah, 2006; Von Hippel, 2005). Unlike the other two constraints, participants were either randomly exposed to the *community evaluation* or *expert evaluation* constraint.

[ Insert Figure 1 about here ]

Below we provide three examples of solutions generated by the community-solvers:

- *"in-ear headphones always slip out of the ears...make them out of a material (similar to plasticine) that takes the shape of the inner ear and gives them a firm grip"*
- *"the headphone should not slip off...the headband should be held in two places...like the straps of a helmet"*
- *"sweat marks on the headphones…use washable removable cover on the headphones, preferably made of breathable material"*

After completing the ideation task, participants were asked a series of manipulation checks about the task features and how they arrived at their solution.

### 3.4. Evaluator Recruitment and Instructions

After the submission window for the ideation contest closed, we sent out a call in the October 2016 newsletter inviting subscribers in Germany and Austria to evaluate the "Ideas of Tomorrow". To evaluate the ideas, any community member could click on a survey link, embedded in the newsletter. Upon clicking on the survey link, individuals were randomly assigned six ideas, one at a time.[3] Following previous research (Moreau & Dahl, 2005; Mueller, Melwani, Loewenstein, & Deal, 2018; Poetz & Schreier, 2012), the quality of ideas were rated for their novelty and usefulness, which was operationalized with solution feasibility. Before rating each idea, evaluators were provided with a definition of the rating criteria: novelty was defined as the uniqueness of the idea compared to ideas that are already available on the market; feasibility was defined as an idea that is technically doable by the Company. After viewing the descriptions, evaluators were then asked to rate each idea for its novelty and feasibility on a 7 point Likert scale. After completing their assigned ideas, evaluators had the option to request another set of randomly assigned solutions.

[3] The first two ideas presented to evaluators were always identical, as a baseline.

Moreover, to avoid source bias, the evaluators were told that the ideas came from a customer survey, experts and engineers. Evaluators were blind to the experiment and treatments. Overall, the call recruited 435 evaluators that evaluated a mean of 6.355 (s.d. = 1.823, min = 2, max = 8) solutions for a total of 2,473 evaluator-submission pairs.

### 3.5. Dependent Variables

***Solution generation.*** To test H1, we use the dependent variable, *Solution generation*, measured as the probability that a participant proposed a solution for the ideation task.

***Solution novelty.*** To test H2, we use the dependent variable, *Solution novelty,* measured using the evaluators' ratings of the solution's novelty on a 7-point Likert scale. Consistent with prior research (e.g., Poetz & Schreier, 2012), we also use the dependent variable *High solution novelty* to measure the probability that a solution receives a top novelty rating of 7 (24.6% of ratings), to identify the most novel solutions.

***Solution usefulness.*** To test H3, we use the dependent variables, *Solution usefulness,* measured using the evaluators' ratings of the solution's feasibility on a 7-point Likert scale. We also use the dependent variables *High solution usefulness* to measure the probability that a solution receives a top feasibility of 7 (47.5% of the ratings), to identify the most useful ideas.

***Solution creativity.*** To test H4, we use the dependent variable, *Solution creativity,* which was represented as a linear combination of the solution's novelty and usefulness (feasibility) depicted in equation (1):

$$Solution\ creativity = Novelty + Usefulness \tag{1}$$

We also use the dependent variable *High solution creativity* to measure the probability that a solution receives a top creativity rating of 14 (i.e., top rating for both novelty and usefulness) in (1), corresponding to 16.2% of all ratings.

### 3.6. Independent Variables

***Number of treatment constraints.*** Our main variable of interest is the *Number of treatment constraints* imposed on the problem. The control condition is always “no constraints”. We also use the squared term, *Number of treatment constraints*$^2$ to test the hypothesized curvilinear relationships in H1 and H4.

***Other Variables and Covariates.*** The analysis strategy relies most critically on the research design’s randomization of constraint treatments and exploitation of multiple evaluations per solution. We use dummy variables for evaluators to control for time-invariant unobserved evaluator characteristics. We also use a number of covariates to control for the solver/participants’ knowledge, motivation, and demographic characteristics. We control for the solvers’ prior knowledge about headphones, their information breadth measured as the total sources they use to stay informed about the newest technologies and trends in the music industry (“Company websites or brochures”, “online magazines or consumer reports”, “online stores”, “blogs or video blogs”, “Facebook”, “microblogging networks, e.g., Twitter, Instagram, etc.”, “friends”, “journals”, “electronic goods retailers, e.g., branches, department stores, etc.”, “specialist events, e.g., conferences, trade fairs, etc.”, “other”), their motivation for participating in the ideation task (“to win a pair of Company headphones”, “winning an Ivy League University t-shirt”, “to have fun”, “reciprocity norms”, “to improve job prospects”), with the motivation categories of needs-driven versus hobbyist-driven informed by Shah (2006), as well as demographic attributes of age and gender. In particular, we control for information breadth, knowledge depth, and demographic characteristics as prior work suggests that technical and social marginality (Jeppesen & Lakhani, 2010), and motivations for participating (Amabile, 2018; Deci & Ryan, 2010; Shalley et al., 2004) may affect a solver's performance and ability to come up with creative ideas.

Table 1 presents the summary statistics for the main covariates, and also shows that the randomization achieved balance on all covariates, except for some small differences in the solvers' motivations for participating. We note that there was an approximately equal number of participants randomly assigned to each condition by constraint type (see Table A1). Table 2 presents the results of the manipulation checks, and shows that the solvers were significantly more likely to indicate that they were exposed to constraint information corresponding to the treatment condition they were assigned to.[4] Note that for the third treatment constraint, *Community evaluation*, the solvers were simply asked whether they were exposed to information about the evaluator, where the difference in means indicates that the community evaluator treatment was more salient (and constraining) than the expert condition.

[ Insert Table 1 about here ]

[ Insert Table 2 about here ]

### 3.7. Estimation Approach

To test H1-H4, we perform OLS regressions to estimate the relationships between the likelihood of generating a solution on the number of treatment constraints imposed on the problem, as well as the quality of the proposed solutions on the number of treatment constraints, where quality was decomposed into solution novelty, usefulness, and creativity.

[4] We also asked solvers whether they knew about the issue (i.e., wearing comfort) prior to the ideation task and whether their proposed solution was an idea they had identified prior to the ideation task. F-tests of the solvers' responses (N = 503) show no significant differences between the experimental conditions (issue known: $F(7,495)$ 0.62, $p = 0.741$; previously identified solution: $F(7,495) = 0.90$, $p = 0.508$).

In H1, our simplest model includes the constraint treatments. We then add controls for solver *i*'s prior knowledge, motivation for participating, and lastly, demographic characteristics. Our final model for the likelihood that solver *i* submits a solution is presented in equation (2):

$$Solution\ generation_i = \beta_0 + \beta_1 Number\ of\ treatment\ constraints_i + \beta_2 Solver\ Attributes_i + \varepsilon_i. \quad (2)$$

Turning to solution quality, once again the simplest model includes the number of treatment constraints, as well as its squared term in the creativity models. We then add evaluator fixed effects ($\alpha_j$) for each evaluator *j* to control for unobserved differences between evaluators. In the regression models examining solution novelty, we control for the solution's usefulness, and for regression models examining solution usefulness, we control for the solution's novelty. Lastly, we add a number of covariates to control for the solver attributes, which include solver *i*'s information sources and knowledge, motivation for participating, and demographic attributes. The final models for novelty, usefulness, and creativity, and the composite creativity score for the solutions are presented in equations (3)-(5), respectively:

$$Solution\ novelty_{ij} = \beta_0 + \beta_1 Number\ of\ treatment\ constraints_i + \beta_2 Solution\ usefulness_{ij} + \beta_3 Solver\ Attributes_i + \alpha_j + \varepsilon_i. \quad (3)$$

$$Solution\ usefulness_{ij} = \beta_0 + \beta_1 Number\ of\ treatment\ constraints_i + \beta_2 Solution\ novelty_{ij} + \beta_3 Solver\ Attributes_i + \alpha_j + \varepsilon_i. \quad (4)$$

$$Solution\ creativity_{ij} = \beta_0 + \beta_1 Number\ of\ treatment\ constraints_i + \beta_2 Number\ of\ treatment\ constraints^2 + \beta_3 Solver\ Attributes_i + \alpha_j + \varepsilon_i. \quad (5)$$

The equations examining the top solutions for each dependent variable are identical except that we replace the continuous dependent variable with the binary variable (=1 if given a top rating of 7). Following recent research, we use OLS or linear probability models (LPM) rather than a logit specification because it yields more interpretable coefficients and allows us to correct for heteroskedasticity in the standard errors (Angrist & Pischke, 2008; Chang, Kirgios, Rai, & Milkman, 2020).

## 4. Results

In this section, we describe our main results testing H1-H4. Table 3 presents the correlations between the main variables.

[ Insert Table 3 about here ]

***Solution Generation and Problem Constraints.*** H1 theorized that solvers are more likely to generate ideas when a problem has an intermediate level of constraints. Table 4 presents the results examining the estimated relationships between the probability of generating a solution and the linear and squared terms of problem constraints imposed on the problem. Model 1 is the baseline model. In Model 2, we add the knowledge and information breadth controls. Model 3 adds motivation controls and finally, Model 4 adds the demographic controls.

In Model 1, we observe that the coefficient for the number of constraint treatments is positive and significant (Model 1: 0.0829, $p < 0.01$), while the coefficient of its squared term is negative and significant (Model 1: -0.0243, $p < 0.05$). Following the suggestion of Haans et al. (2016) and Lind and Mehlum (2010), we further confirm the presence of an inverted U-shaped relationship between the probability of generating a solution and problem constraints by calculating the slope of the curve to the left and right of its turning point (Haans, Pieters, & He, 2016; Lind & Mehlum, 2010). The slope at the lower bound (minimum value) is positive and significant ($\beta = 0.083$, $p < 0.003$) and the slope at the upper bound (maximum value) is negative and significant ($\beta = -0.063$, $p < 0.024$). The inflection point is 1.703 and 49.7% of the observations lie beyond this point. Using the utest.ado command in stata, developed by Lind and Mehlum (2010), we find a significant presence of an inverse U-shaped relationship ($p = 0.024$) (Lind & Mehlum, 2010). As an additional test, we derive Fieller's (1954) confidence interval around the maximum of the curve to determine whether the maximum lies within the range of the treatment constraints variable. The extreme values of the confidence interval are [1.294, 2.957], which is within the range of the main independent variable (Fieller, 1954). Thus, we find evidence that the significant squared term signals negative returns to an increasing number of constraints beyond a threshold. Figure 2 plots the estimated relationships with 95% CIs between the probability of generating a solution and the number of treatment constraints from Model 1. We observe that compared to no problem constraints, having some constraints increases a solver's likelihood of generating a solution by about 6pp, or 1.5 times more than the baseline submission rate with no constraints (i.e., control condition).

[ Insert Figure 2 about here ]

In Model 2-4, we add covariates for the solvers' prior knowledge of head phones and information breadth, motivation for participating, and demographics. Given that the number of constraints is exogenously assigned to the solvers, controls add precision to the estimated relationships. The coefficients for the number of treatment constraints and its squared term remain significant and consistent across the models. Taken altogether, these results strongly support H1, which predicts that solvers are more likely to generate solutions when the problem has a moderate level of constraints.

[ Insert Table 4 about here ]

In Tables 5-6, we turn to testing H2-H3, which theorize the effects of problem constraints on the components of idea quality, solution novelty (Table 5) and usefulness (Table 6). In both tables, the dependent variable in Models 1-4 corresponds to the novelty, usefulness and creativity scores for each evaluator, whereas the dependent variable in Models 5-8 is a binary variable corresponding to whether an idea received a top rating of 7. Models 1 and 5 are the baseline models with the number of treatment constraints, Models 2 and 6 add rater fixed effects, Models 3 and 7 add controls for the usefulness (Table 5) and novelty (Table 6) of the solution, and lastly, Models 4 and 8 add solver attributes as controls.

***Solution Novelty and Problem Constraints.*** In H2, we predict adding problem constraints would lead to less novel solutions. Table 5 presents the results examining the estimated relationships between solution novelty and the number of problem constraints. Model 1 indicates that higher levels of constraints decrease the novelty ratings of the solution by 0.152 points (Model 1: -0.151, $p < 0.01$). The coefficient remains consistent and highly significant in Model 2 which adds the evaluator fixed effects (Model 2: -0.157, $p < 0.01$). Next, Model 3 controls for the solution's usefulness, and shows that the coefficient for treatment coefficients remains stable and significant (Model 3: -0.157, $p < 0.01$) and that solution usefulness is orthogonally related to its novelty (Model 3: -0.0153, *ns*). Lastly, Model 4 controls for solver attributes, and we observe that the coefficient for the treatment constraints variable remains negative and significant (Model 4: -0.121, $p < 0.01$). Figure 3 plots the estimated relationships with 95% CIs between solution novelty and the number of treatment constraints from Model 2, and highlights the negative, linear relationship between problem constraints and novelty.

[ Insert Table 5 about here ]

[ Insert Figure 3 about here ]

Turning to the most novel solutions that received the top novelty rating, Model 5 shows that the number of constraint treatments has no significant effect on the most novel solutions

(Model 5: -0.0112, *ns*). The coefficient for the constraint treatments variable is also not significant in Models 5-8, which adds evaluator fixed effects, and controls for the solution's usefulness and solver attributes. Taken altogether, we find strong support that constraints decrease the average novelty of proposed solutions, but there is no negative impact of problem constraints on the most novel solutions. Taken altogether, we find support for H2.

***Solution Usefulness and Problem Constraints.*** In H3, we theorized that problems with more constraints would lead to more useful solutions. Table 6 presents the results examining the estimated relationships between solution usefulness and the number of treatment constraints. Model 1 indicates that higher levels of constraints have no effect on the solution's usefulness (Model 1: 0.023, *ns*). The results in Models 2-4 are consistent. Turning to highly useful solutions in Model 5, once again, there is no significant relationship between the number of treatment constraints and the most useful solutions (Model 5: 0.0120, *ns*). The results in Models 6-8 are consistent. Thus, we do not find support for H3.

[ Insert Table 6 about here ]

***Solution Creativity and Problem Constraints.*** H4 theorized that an intermediate level of problem constraints would lead to more creative solutions. Table 7 presents the creativity results. In Models 1-3, the dependent variable is the solution's creativity, and in Models 4-6, the dependent variable is the most creative solutions receiving the top creativity score of 14. Models 1 and 3 are the baseline models, which includes the number of treatment constraints. Models 2 and 5 add evaluator fixed effects, and Models 3 and 6 add solver controls. Turning to the solution creativity in Model 1, we observe that there is a positive but not significant effect of the number of treatment constraints (Model 1: 0.237, *ns*) and a negative and significant effect of its squared term (Model 1: -0.116, $p < 0.05$) on the solution's creativity. That said, neither term is significant in Model 2 or Model 3, which add evaluator fixed effects and solver attributes.

Turning to the most creative solutions, we observe in Model 4 that the linear term for the number of treatment constraints is positive and significant (Model 4: 0.0616, $p < 0.05$), and the squared term is negative and significant (Model 4: -0.0204, $p < 0.05$), suggesting the presence of an inverse U-shape relationship. To confirm the presence of the inverted U-shape relationship, we conduct the following tests by calculating the slope of the curve to the left and right of its turning point as well as the 95% CI for the extreme point (Haans et al., 2016; Lind & Mehlum, 2010). First, we find that the minimum value at the lower bound is positive and significant ($\beta$ = 2.189, $p < 0.05$) and the maximum value at the upper bound is negative and significant ($\beta$ = -2.332, $p < 0.01$). Second, the extreme point is 1.505 [0.652, 2.133], with the Fieller (1954)'s 95% CI for the extreme point showing that it is within the range of the treatment constraints variable (Fieller, 1954). Therefore, we confirm that an inverted U-shape relationship exists in Model 4 between the most useful solutions and the number of treatment constraints.

In Model 5, we add evaluator FE. The linear term for the number of treatment constraints is positive, but not significant (Model 5: 0.0431, *ns*), and its squared term is negative and marginally significant (Model 5: 0.0505, $p < 0.10$). Lastly, in our final, and most stringent specification in Model 6, which adds solver controls, we observe that the linear term for the number of treatment constraints is positive and marginally significant (Model 6: 0.0505, $p < 0.10$), and its squared term is negative and marginally significant (Model 6: -0.0159, $p < 0.10$).[5] Figure 4 plots the relationship between the most creative solutions and the number of treatment

[5] We note that the slope at the minimum value at the lower bound is positive and significant ( = 1.737, $p < 0.05$), and the slope at the maximum value at the upper bound is negative and significant ( = -1.667, $p < 0.05$). That said, the Fieller (1954)'s 95% CI for the extreme point is outside the range of the treatment constraints variable.

constraints in Model 6, and illustrates that having some constraints improve the likelihood of generating one of the most creative solutions by about 3-4pp. Taken altogether, we find evidence of an inverted curvilinear relationship between the most creative solutions and the number of problem constraints, and find partial support for H4.

[ Insert Table 7 about here ]

## 5. Discussion

Scholars of creativity and innovation have long been interested in the factors that lead to productive creative solving activities (Amabile, 1996; Criscuolo, Dahlander, Grohsjean, & Salter, 2017; Fleming et al., 2007; Jeppesen & Lakhani, 2010; Perry-Smith, 2006). Although the number and quality of alternative solutions largely depend on how problems are formulated to be solved (Baer et al., 2013; Csikszentmihalyi & Getzels, 1971), the literature has predominantly focused on the problem solving stage (Amabile, 1996; Jeppesen & Lakhani, 2010; March, 1991; Shalley et al., 2004), which occurs *after* a problem has been identified and formulated (Dillon, 1982; Runco, 1994). Consequently, research that systematically examines the links between the problem formulation and problem solving stages remains relatively obscure (Ehls, Polier, & Herstatt, 2020). To advance understanding, this paper focuses on how problem constraints may affect the quantity and quality of solutions generated by creative problem solving.

Overall, our results indicate that some problem constraints benefit both the generation and selection of the high quality ideas during the creative problem solving process. First, we find that intermediate levels of constraints increase the quantity of solutions: having some constraints causally increases the likelihood that a solver submits a solution by 6 pp or 1.5 times more than problems with no constraints. Therefore, constraints benefit idea quantity up until a certain threshold, after which there are decreasing returns to additional constraints. Second, examining the novelty and usefulness of proposed solutions, we show that while an increase in problem constraints decreases the average solution novelty, constraints do not change the distribution of the most novel ideas. We also find no significant relationship between the number of problem constraints and the usefulness of a solution. This suggests that adding problem constraints can increase idea quantity without dampening the novelty or usefulness of the most unique ideas. Third, we find evidence of an inverted U-shaped relationship between the number of problem constraints and the most creative solutions, with some constraints increasing the likelihood of coming up with one of the most creative solutions by 3-4pp compared to problems with no constraints. The significance of our relationships between problem constraints and the best ideas is critical, as firms often select a few high quality solutions to be implemented in their innovation strategy (Baer, 2012).

Our results offer several contributions. First, we contribute to the literature on the knowledge-based view of the firm, which emphasizes the problem as the basic unit of analysis (Baer et al., 2013; Nickerson & Zenger, 2004). Despite the call for great work examining how problem formulation is linked to problem solving, there is relatively little work that examines these important relationships (Acar et al., 2019). By focusing on the role of problem constraints, we advance understanding of how problem formulation affects different activities associated with the creative problem solving process. In particular, we are able to offer greater insight into whether and when an inverted U-shaped relationship exists between problem constraints and creative ideas, and how problem constraints conceptualized during the formulation stage may have differentiated effects on either the stage of problem solving via solution generation and solution quality, as well as the different components of solution quality in the context of creativity. In contrast, prior work tends to focus on the factors that lead to greater productivity of ideas (Bayus, 2013; Jeppesen & Lakhani, 2010; Piezunka & Dahlander, 2015), with little regard to how a problem is formulated (Baer et al., 2013; Ehls et al., 2020), or on identifying high quality solutions, typically focusing on novelty (Boudreau et al., 2016; Criscuolo et al., 2017; Uzzi & Spiro, 2005). By considering the role of usefulness in solution generation, our work presents an alternative explanation to recent work on evaluation and selection that suggests that ideas with intermediate levels of novelty are often preferred to highly novel solutions (Boudreau et al., 2016; Criscuolo et al., 2017). One potential reason for these findings may be related to the notion that evaluators are often trying to identify the most creative ideas that effectively balance both novelty and usefulness, rather than purely novel solutions, which may be unique but not useful or relevant to the problem domain (Jeppesen & Lakhani, 2010; Lane et al., 2020).

Second, we contribute to the open innovation and crowdsourcing literature (Henkel, Schöberl, & Alexy, 2014; Laursen & Salter, 2006; Piezunka & Dahlander, 2015; Poetz & Schreier, 2012; Shah, 2006; Von Hippel, 2005) by showing that problem formulation is likely to influence the breadth and characteristics of crowd participation, affecting both the number of solutions and range of perspectives. In contrast, most of the literature to date has focused on how broadcast search may attract greater marginality (Jeppesen & Lakhani, 2010), the effects of solution quantity and diversity on evaluators' selection behaviors (Piezunka & Dahlander, 2015), or the implications of end-user participation on firm innovation (Chatterji and Fabrizio, 2014, von Hippel, 2006). Our work suggests that crowdsourcing and open innovation scholars ought to pay closer attention to the problem discovery and formulation stage, which is likely to determine *who* participates and the *quality* of their ideas.

Third, we make practical, managerial contributions to the innovation literature. Managers often need to balance their innovation strategies to effectively combine exploration and exploitation strategies to sustain their competitive advantage (Gupta et al., 2006; He & Wong, 2004; March, 1991; Rosenkopf & Nerkar, 2001). We suggest that how a problem is formulated, via the number of problem constraints imposed on the problem, will causally affect the quantity and quality of the ideas generated. Although a firm's expertise, strategy, and/or domain may ultimately determine how novelty and usefulness are prioritized, we show that problem constraints are causally related to whether a firm's new product development strategy veers closer to radical versus incremental innovation.

Although this research exploits a large field experiment with community idea generators and evaluators, and offers valuable insights into the nature of the relationships between problem constraints and the creativity process, it also has some limitations. First, although we exogenously varied the number of constraints imposed on the problem, the *type* of constraint may affect a solution's creativity as much as the number of constraints. For example, Acar et al. (2019) suggest a typology for classifying constraints as input, process and output oriented, which may differentially affect solvers' motivation and cognitive behaviors. In addition, research from behavioral economics and psychology suggests that individuals tend to process information sequentially rather than comprehensively (Kahneman, 2011). This suggests that the order that the treatment constraints were presented may affect how the constraints are processed by solvers as they search for solutions. While our work is relatively agnostic to the type of constraint and the order of constraints, we do note that compared to the control condition (no constraints), the treatment conditions of limiting solutions and community evaluation are more effective in increasing submissions than providing directions, which included examples of sample solutions. These sample solutions may have limited the solvers' ideas to explore outside of these solution domains. Future research can seek to place greater specificity into how the type and sequence of constraints imposed on a problem may influence the relative novelty, usefulness and creativity of the generated solutions. Another possible avenue for future work would be to examine other types of problem solving processes. Our work focused on formal problem solving processes where a problem is formulated prior to it being solved. In contrast, von Hippel and von Krogh (2016) propose that under informal problem solving, a need and a solution are discovered and tested together as a need-solution pair – such that "formulating a need" and "formulating a problem" are really a single process (p. 211). In the context of creativity and constraints, future work can examine to what extent need-formulation also puts constraints on the viable solutions that emerge from solving the need.

A second limitation of this study is that although we examine the creative problem solving as a process of interconnected components, we are not able to directly observe which solutions were ultimately implemented (due to company privacy reasons). Therefore, we cannot make causal claims about how the effects of constraints on earlier stages of creativity production is directly related to their implementation decisions. As the criteria for novel ideas may differ from the subsequent economic value (Baer, 2012; Kaplan & Vakili, 2015), future research can seek to examine this link more closely to identify whether and how problem constraints influence which ideas are generated, selected, implemented, and ultimately rewarded as innovations.

Third, our study focuses on consumer electronics where the nature of innovation is unlike those found in more technical or uncertain fields, such as bench science or early-stage R&D projects (Criscuolo et al., 2017; Fleming et al., 2007; Singh & Fleming, 2010), where the creative problem solving process is subject to longer discovery times, failure rates, and for which it has been documented that paradigmatic constraints may be cognitively confining on solvers' creativity (Chai, 2017). Hence, another fruitful area for future work is to investigate how problem constraints affect creativity across different domains and industries.

Fourth, we conducted this study in the ecosystem of the company and not within the engineering and design staff of the company. The limitations of our causal inference design necessarily moved us to focus on the community. Although we are comfortable with the external validity of our findings to open and crowdsourced settings, we remain cautious about the implications of these findings to internal settings - which is another promising area for future work to investigate.

In summary, we offer this research as a new perspective into the effects of problem formulation on the process of generating creative ideas. By highlighting the important role of constraints on both the quantity and quality of generated solutions, our research offers important insights into the nature of the creative problem solving process for firm innovation.

## 6. References


Acar, O. A., Tarakci, M., & van Knippenberg, D. 2019. Creativity and innovation under constraints: A cross-disciplinary integrative review. ***Journal of Management***, 45(1): 96–121.

Acar, O. A., & van den Ende, J. 2016. Knowledge distance, cognitive-search processes, and creativity: The making of winning solutions in science contests. ***Psychological Science***, 27(5): 692–699.

Amabile, T. M. 1983. Brilliant but cruel: Perceptions of negative evaluators. ***Journal of Experimental Social Psychology***, 19(2): 146–156.

Amabile, T. M. 1996. ***Creativity and innovation in organizations***.

Amabile, T. M. 1998. ***How to kill creativity***, vol. 87. Harvard Business School Publishing Boston, MA.

Amabile, T. M. 2018. ***Creativity in context: Update to the social psychology of creativity***. Routledge.

Amabile, T. M., Conti, R., Coon, H., Lazenby, J., & Herron, M. 1996. Assessing the work environment for creativity. ***Academy of Management Journal***, 39(5): 1154–1184.

Angrist, J. D., & Pischke, J.-S. 2008. ***Mostly harmless econometrics: An empiricist's companion***. Princeton university press.

Baer, M. 2012. Putting creativity to work: The implementation of creative ideas in organizations. ***Academy of Management Journal***, 55(5): 1102–1119.

Baer, M., Dirks, K. T., & Nickerson, J. A. 2013. Microfoundations of strategic problem formulation. ***Strategic Management Journal***, 34(2): 197–214.

Baron, J. 2000. ***Thinking and deciding***. Cambridge University Press.
Bayus, B. L. 2013. Crowdsourcing new product ideas over time: An analysis of the Dell IdeaStorm community. ***Management Science***, 59(1): 226–244.
Benner, M. J., & Tushman, M. 2002. Process management and technological innovation: A longitudinal study of the photography and paint industries. ***Administrative Science Quarterly***, 47(4): 676–707.
Boudreau, K. J., Guinan, E. C., Lakhani, K. R., & Riedl, C. 2016. Looking across and looking beyond the knowledge frontier: Intellectual distance, novelty, and resource allocation in science. ***Management Science***, 62(10): 2765–2783.
Caniëls, M. C., & Rietzschel, E. F. 2015. Organizing creativity: Creativity and innovation under constraints. ***Creativity and Innovation Management***, 24(2): 184–196.
Chai, S. 2017. Near misses in the breakthrough discovery process. ***Organization Science***, 28(3): 411–428.
Chang, E. H., Kirgios, E. L., Rai, A., & Milkman, K. L. 2020. The Isolated Choice Effect and Its Implications for Gender Diversity in Organizations. ***Management Science***.
Chatterji, A. K., & Fabrizio, K. R. 2014. Using users: When does external knowledge enhance corporate product innovation? ***Strategic Management Journal***, 35(10): 1427–1445.
Chua, R. Y.-J., & Iyengar, S. S. 2008. Creativity as a matter of choice: Prior experience and task instruction as boundary conditions for the positive effect of choice on creativity. ***The Journal of Creative Behavior***, 42(3): 164–180.
Criscuolo, P., Dahlander, L., Grohsjean, T., & Salter, A. 2017. Evaluating novelty: The role of panels in the selection of R&D projects. ***Academy of Management Journal***, 60(2): 433–460.
Cromwell, J. R., Amabile, T. M., & Harvey, J.-F. 2018. An Integrated Model of Dynamic Problem Solving Within Organizational Constraints. ***Individual Creativity in the Workplace***: 53–81. Elsevier.
Csikszentmihalyi, M. 1997. Flow and the psychology of discovery and invention. ***HarperPerennial, New York***, 39.
Csikszentmihalyi, M., & Getzels, J. W. 1971. Discovery-oriented behavior and the originality of creative products: A study with artists. ***Journal of Personality and Social Psychology***, 19(1): 47.
Cummiskey, B. M., & Baer, M. 2018. Bounded creativity: A theory of the effects of constraints on the production of new ideas. ***Academy of Management Proceedings***, 2018(1): 15243. Academy of Management Briarcliff Manor, NY 10510.
Cyert, R. M., & March, J. G. 1963. A behavioral theory of the firm. ***Englewood Cliffs, NJ***, 2(4): 169–187.
Deci, E. L., & Ryan, R. M. 2010. Intrinsic motivation. ***The Corsini Encyclopedia of Psychology***, 1–2.
Dewey, J. 1997. ***How we think***. Courier Corporation.
Dillon, J. T. 1982. Problem finding and solving. ***The Journal of Creative Behavior***.
Ehls, D., Polier, S., & Herstatt, C. 2020. Reviewing the field of external knowledge search for innovation: Theoretical underpinnings and future (re-) search directions. ***Journal of Product Innovation Management***, 37(5): 405–430.
Felin, T., & Zenger, T. R. 2014. Closed or open innovation? Problem solving and the governance choice. ***Research Policy***, 43(5): 914–925.

Fieller, E. C. 1954. Some problems in interval estimation. ***Journal of the Royal Statistical Society: Series B (Methodological)***, 16(2): 175–185.
Fleming, L., Mingo, S., & Chen, D. 2007. Collaborative brokerage, generative creativity, and creative success. ***Administrative Science Quarterly***, 52(3): 443–475.
Getzels, J. W. 1975. Problem-finding and the inventiveness of solutions. ***The Journal of Creative Behavior***.
Getzels, J. W., & Csikszentmihalyi, M. 1975. From problem solving to problem finding. ***Perspectives in Creativity***, 90: 116.
Gigerenzer, G., & Gaissmaier, W. 2011. Heuristic decision making. ***Annual Review of Psychology***, 62: 451–482.
Girotra, K., Terwiesch, C., & Ulrich, K. T. 2010. Idea generation and the quality of the best idea. ***Management Science***, 56(4): 591–605.
Grant, A. M., & Berry, J. W. 2011. The necessity of others is the mother of invention: Intrinsic and prosocial motivations, perspective taking, and creativity. ***Academy of Management Journal***, 54(1): 73–96.
Gupta, A. K., Smith, K. G., & Shalley, C. E. 2006. The interplay between exploration and exploitation. ***Academy of Management Journal***, 49(4): 693–706.
Haans, R. F., Pieters, C., & He, Z.-L. 2016. Thinking about U: Theorizing and testing U-and inverted U-shaped relationships in strategy research. ***Strategic Management Journal***, 37(7): 1177–1195.
Haas, M. R., Criscuolo, P., & George, G. 2015. Which problems to solve? Online knowledge sharing and attention allocation in organizations. ***Academy of Management Journal***, 58(3): 680–711.
Harvey, S. 2014. Creative synthesis: Exploring the process of extraordinary group creativity. ***Academy of Management Review***, 39(3): 324–343.
He, Z.-L., & Wong, P.-K. 2004. Exploration vs. Exploitation: An empirical test of the ambidexterity hypothesis. ***Organization Science***, 15(4): 481–494.
Henkel, J., Schöberl, S., & Alexy, O. 2014. The emergence of openness: How and why firms adopt selective revealing in open innovation. ***Research Policy***, 43(5): 879–890.
Hirst, G., Van Knippenberg, D., & Zhou, J. 2009. A cross-level perspective on employee creativity: Goal orientation, team learning behavior, and individual creativity. ***Academy of Management Journal***, 52(2): 280–293.
Isen, A. M., Daubman, K. A., & Nowicki, G. P. 1987. Positive affect facilitates creative problem solving. ***Journal of Personality and Social Psychology***, 52(6): 1122.
Iyengar, S. S., & Lepper, M. R. 2000. When choice is demotivating: Can one desire too much of a good thing? ***Journal of Personality and Social Psychology***, 79(6): 995.
Jeppesen, L. B., & Lakhani, K. R. 2010. Marginality and problem-solving effectiveness in broadcast search. ***Organization Science***, 21(5): 1016–1033.
Joyce, C. K. 2009. The blank page: Effects of constraint on creativity. ***Available at SSRN 1552835***.
Kahneman, D. 1973. ***Attention and effort***, vol. 1063. Citeseer.
Kahneman, D. 2011. ***Thinking, fast and slow***. Macmillan.
Kaplan, S., & Vakili, K. 2015. The double-edged sword of recombination in breakthrough innovation. ***Strategic Management Journal***, 36(10): 1435–1457.

Katila, R., & Ahuja, G. 2002. Something old, something new: A longitudinal study of search behavior and new product introduction. ***Academy of Management Journal***, 45(6): 1183–1194.

Lane, J., Teplitskiy, M., Gray, G., Ranu, H., Menietti, M., et al. 2020. When Do Experts Listen to Other Experts? The Role of Negative Information in Expert Evaluations for Novel Projects. ***Harvard Business School Technology & Operations Mgt. Unit Working Paper***, (21–007).

Laursen, K., & Salter, A. 2006. Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. ***Strategic Management Journal***, 27(2): 131–150.

Leiblein, M. J., & Macher, J. T. 2009. The problem solving perspective: A strategic approach to understanding environment and organization. ***Economic institutions of strategy***. Emerald Group Publishing Limited.

Levinthal, D., & March, J. G. 1981. A model of adaptive organizational search. ***Journal of Economic Behavior & Organization***, 2(4): 307–333.

Li, Q., Maggitti, P. G., Smith, K. G., Tesluk, P. E., & Katila, R. 2013. Top management attention to innovation: The role of search selection and intensity in new product introductions. ***Academy of Management Journal***, 56(3): 893–916.

Lind, J. T., & Mehlum, H. 2010. With or without U? The appropriate test for a U-shaped relationship. ***Oxford Bulletin of Economics and Statistics***, 72(1): 109–118.

Macher, J. T., & Boerner, C. 2012. Technological development at the boundaries of the firm: A knowledge-based examination in drug development. ***Strategic Management Journal***, 33(9): 1016–1036.

March, J. G. 1991. Exploration and exploitation in organizational learning. ***Organization Science***, 2(1): 71–87.

Mayer, M. 2006, February 13. Creativity Loves Constraints. ***Bloomberg Business Week***. https://www.bloomberg.com/news/articles/2006-02-12/creativity-loves-constraints.

Moreau, C. P., & Dahl, D. W. 2005. Designing the solution: The impact of constraints on consumers' creativity. ***Journal of Consumer Research***, 32(1): 13–22.

Mueller, J., Melwani, S., Loewenstein, J., & Deal, J. J. 2018. Reframing the decision-makers' dilemma: Towards a social context model of creative idea recognition. ***Academy of Management Journal***, 61(1): 94–110.

Newell, A., & Simon, H. A. 1972. ***Human problem solving***, vol. 104. Prentice-Hall Englewood Cliffs, NJ.

Nickerson, J. A., & Zenger, T. R. 2004. A knowledge-based theory of the firm—The problem-solving perspective. ***Organization Science***, 15(6): 617–632.

Nonaka, I., & Von Krogh, G. 2009. Perspective—Tacit knowledge and knowledge conversion: Controversy and advancement in organizational knowledge creation theory. ***Organization Science***, 20(3): 635–652.

Ocasio, W. 1997. Towards an attention-based view of the firm. ***Strategic Management Journal***, 18(S1): 187–206.

Onarheim, B. 2012. Creativity from constraints in engineering design: Lessons learned at Coloplast. ***Journal of Engineering Design***, 23(4): 323–336.

Perry-Smith, J. E. 2006. Social yet creative: The role of social relationships in facilitating individual creativity. ***Academy of Management Journal***, 49(1): 85–101.

Piezunka, H., & Dahlander, L. 2015. Distant search, narrow attention: How crowding alters organizations' filtering of suggestions in crowdsourcing. ***Academy of Management Journal***, 58(3): 856–880.

Poetz, M. K., & Schreier, M. 2012. The value of crowdsourcing: Can users really compete with professionals in generating new product ideas? ***Journal of Product Innovation Management***, 29(2): 245–256.

Reitman, W. R. 1965. ***Cognition and thought: An information processing approach.***

Rhee, L., & Leonardi, P. M. 2018. Which pathway to good ideas? A n attention-based view of innovation in social networks. ***Strategic Management Journal***, 39(4): 1188–1215.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2006. Productivity is not enough: A comparison of interactive and nominal brainstorming groups on idea generation and selection. ***Journal of Experimental Social Psychology***, 42(2): 244–251.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2007. Relative accessibility of domain knowledge and creativity: The effects of knowledge activation on the quantity and originality of generated ideas. ***Journal of Experimental Social Psychology***, 43(6): 933–946.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2014. Effects of problem scope and creativity instructions on idea generation and selection. ***Creativity Research Journal***, 26(2): 185–191.

Rosenkopf, L., & Nerkar, A. 2001. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. ***Strategic Management Journal***, 22(4): 287–306.

Rosso, B. D. 2014. Creativity and constraints: Exploring the role of constraints in the creative processes of research and development teams. ***Organization Studies***, 35(4): 551–585.

Runco, M. A. 1994. ***Problem finding, problem solving, and creativity***. Greenwood Publishing Group.

Schilling, M. A., & Green, E. 2011. Recombinant search and breakthrough idea generation: An analysis of high impact papers in the social sciences. ***Research Policy***, 40(10): 1321–1331.

Schwartz, B. 2004. ***The paradox of choice: Why more is less***. Ecco New York.

Shah, S. K. 2006. Motivation, governance, and the viability of hybrid forms in open source software development. ***Management Science***, 52(7): 1000–1014.

Shalley, C. E. 1991. Effects of productivity goals, creativity goals, and personal discretion on individual creativity. ***Journal of Applied Psychology***, 76(2): 179.

Shalley, C. E. 1995. Effects of coaction, expected evaluation, and goal setting on creativity and productivity. ***Academy of Management Journal***, 38(2): 483–503.

Shalley, C. E., Zhou, J., & Oldham, G. R. 2004. The effects of personal and contextual characteristics on creativity: Where should we go from here? ***Journal of Management***, 30(6): 933–958.

Simon, H. A. 1978. Information-processing theory of human problem solving. ***Handbook of Learning and Cognitive Processes***, 5: 271–295.

Simon, H. A. 1983. Discovery, invention, and development: Human creative thinking. ***Proceedings of the National Academy of Sciences of the United States of America***, 80(14): 4569.

Simon, H. A., & Newell, A. 1971. Human problem solving: The state of the theory in 1970. ***American Psychologist***, 26(2): 145.

Sine, W. D., Haveman, H. A., & Tolbert, P. S. 2005. Risky business? Entrepreneurship in the new independent-power sector. ***Administrative Science Quarterly***, 50(2): 200–232.
Singh, J., & Fleming, L. 2010. Lone inventors as sources of breakthroughs: Myth or reality? ***Management Science***, 56(1): 41–56.
Stokes, P. D. 2001. Variability, constraints, and creativity: Shedding light on Claude Monet. ***American Psychologist***, 56(4): 355.
Stokes, P. D. 2005. ***Creativity from constraints: The psychology of breakthrough***. Springer Publishing Company.
Ulrich, K. T. 2011. ***Design: Creation of artifacts in society***. Karl T. Ulrich.
Unsworth, K. 2001. Unpacking creativity. ***Academy of Management Review***, 26(2): 289–297.
Uzzi, B., & Spiro, J. 2005. Collaboration and creativity: The small world problem. ***American Journal of Sociology***, 111(2): 447–504.
Von Hippel, E. 2005. Open source software projects as user innovation networks. ***Perspectives on Free and Open Source Software***, 267–278.
Von Hippel, E., & Von Krogh, G. 2016. Crossroads—Identifying viable “need–solution pairs”: Problem solving without problem formulation. ***Organization Science***, 27(1): 207–221.
Ward, T. B. 1994. Structured imagination: The role of category structure in exemplar generation. ***Cognitive Psychology***, 27(1): 1–40.
Ward, T. B., Smith, S. M., & Finke, R. A. 1999. Creative cognition. ***Handbook of Creativity***, 189: 212.
Weisberg, R. W. 2006. ***Creativity: Understanding innovation in problem solving, science, invention, and the arts***. John Wiley & Sons.
Zhang, X., & Bartol, K. M. 2010. Linking empowering leadership and employee creativity: The influence of psychological empowerment, intrinsic motivation, and creative process engagement. ***Academy of Management Journal***, 53(1): 107–128.
Zhou, J., Wang, X. M., Bavato, D., Tasselli, S., & Wu, J. 2019. Understanding the receiving side of creativity: A multidisciplinary review and implications for management research. ***Journal of Management***, 45(6): 2570–2595.

Table 1. Summary Statistics By Randomized Exposures to Constraint Treatments

| Variable | Mean | SD | Min | Max | Statistical Test |
|---|---|---|---|---|---|
| | | | | | Study 1 (N = 2,473) |
| Prior knowledge | 4.763 | 2.388 | 0 | 10 | F(3,1829) = 0.76, *p* =0.52 |
| Information breadth | 3.318 | 1.643 | 1 | 10 | F(3,1829) = 0.32, *p* = 0.81 |
| Motivation – fun | 4.932 | 1.874 | 1 | 7 | F(3,1756) = 0.27, *p* = 0.85 |
| Motivation – job | 1.572 | 1.317 | 1 | 7 | F(3,1756) = 3.24, *p* = 0.02 |
| Motivation – win headphones | 4.478 | 2.230 | 1 | 7 | F(3,1756) = 0.23, *p* = 0.89 |
| Motivation – win t-shirt | 6.179 | 1.402 | 1 | 7 | F(3,1759) = 2.59, *p* = 0.05 |
| Motivation – reciprocity | 4.802 | 1.800 | 1 | 7 | F(3,1756) = 3.38, *p* = 0.02 |
| Age | 47.320 | 13.049 | 19 | 80 | F(3,1115) = 1.81, *p* = 0.14 |
| Gender | 0.106 | 0.307 | 0 | 1 | $\chi^2(3, N = 1115) = 2.65, p = 0.45$ |

Note: Descriptive statistics are reported for the full sample.
N's for conditions: control = 229, 1 constraint = 693, 2 constraints = 682, 3 constraints = 229.

Table 2. Manipulation Checks By Treatment Constraint Condition (N = 503)

| | Constraint Not Given | Constraint Given | Diff. (two-tailed t-test) |
|---|---|---|---|
| Providing directions | M = 3.209 (s.d. = 0.122); N = 916 | M = 4.004 (s.d. = 0.134); N = 917 | -0.795*** |
| Limiting solutions | M = 2.814 (s.d. = 0.120); N = 917 | M = 3.222 (s.d. = 0.123); N = 916 | -0.408** |
| Community evaluation | M = 2.882 (s.d. = 0.120); N = 922 | M 3.375 (s.d. = 0.130); N = 911 | -0.493*** |

Table 3. Correlation Table of Main Variables (Study 1; N = 2,473)

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Solution rating** | | | | | | | | | | | | |
| 1 | Novelty | 1.000 | | | | | | | | | | | |
| 2 | Usefulness | 0.066 | 1.000 | | | | | | | | | | |
| 3 | Creativity | 0.860 | 0.484 | 1.000 | | | | | | | | | |
| | **Treatment** | | | | | | | | | | | | |
| 4 | # of constraints | -0.053 | 0.010 | -0.046 | 1.000 | | | | | | | | |
| | **Knowledge** | | | | | | | | | | | | |
| 5 | Headphones | -0.030 | -0.039 | -0.041 | -0.050 | 1.000 | | | | | | | |
| 6 | Info. Sources | 0.018 | -0.009 | 0.014 | 0.066 | 0.349 | 1.000 | | | | | | |
| | **Motivation** | | | | | | | | | | | | |
| 7 | Fun | -0.045 | 0.014 | -0.029 | 0.029 | 0.046 | -0.054 | 1.000 | | | | | |
| 8 | Job | 0.000 | -0.044 | -0.021 | -0.023 | 0.174 | 0.106 | -0.123 | 1.000 | | | | |
| 9 | Win headphones | -0.019 | -0.017 | -0.012 | 0.045 | 0.011 | -0.005 | -0.003 | 0.118 | 1.000 | | | |
| 10 | Win t-shirt | 0.020 | -0.013 | 0.018 | 0.081 | -0.102 | -0.135 | -0.038 | 0.073 | 0.261 | 1.000 | | |
| 11 | Reciprocity | -0.004 | 0.007 | 0.008 | -0.098 | 0.253 | 0.127 | -0.065 | 0.237 | 0.086 | 0.034 | 1.000 | |
| | **Demographics** | | | | | | | | | | | | |
| 12 | Age | -0.043 | 0.024 | -0.032 | -0.111 | -0.116 | -0.011 | 0.041 | -0.211 | 0.094 | 0.052 | -0.169 | 1.000 |
| 13 | Female | 0.039 | 0.013 | 0.038 | -0.014 | -0.105 | 0.047 | 0.089 | -0.027 | -0.051 | -0.073 | -0.008 | -0.180 |

Note: correlations > |0.04| are statistically significant at $p < 0.05$

Table 4. OLS Regression Models of Probability of Generating a Solution on Treatment Constraints and Constraints$^2$

| | Dependent Variable: Probability of Generating a Solution | | | |
|---|---|---|---|---|
| VARIABLES | Model 1<br># constraints | Model 2<br>Info & knowledge | Model 3<br>Motivation | Model 4<br>Demographics |
| # constraints | 0.0829*** | 0.0831*** | 0.0858*** | 0.138*** |
| | (0.0298) | (0.0294) | (0.0301) | (0.0477) |
| # constraints$^2$ | -0.0243** | -0.0237** | -0.0235** | -0.0456*** |
| | (0.00977) | (0.00961) | (0.00995) | (0.0152) |
| Prior knowledge | | 0.0177*** | 0.0151*** | 0.0144** |
| | | (0.00409) | (0.00435) | (0.00631) |
| # of info sources | | 0.0170*** | 0.0137** | 0.0232** |
| | | (0.00632) | (0.00667) | (0.00993) |
| Motivation - fun | | | -0.00489 | -0.00480 |
| | | | (0.00490) | (0.00714) |
| Motivation - job | | | -0.00933 | -0.0133 |
| | | | (0.00717) | (0.0110) |
| Motivation - prize | | | -0.00397 | 6.68e-05 |
| | | | (0.00652) | (0.00964) |
| Motivation - headphones | | | 0.00115 | -0.00150 |
| | | | (0.00437) | (0.00654) |
| Motivation - rec | | | 0.0204*** | 0.0286*** |
| | | | (0.00476) | (0.00728) |
| Age | | | | -0.00474*** |
| | | | | (0.00110) |
| Female | | | | -0.0224 |
| | | | | (0.0425) |
| Constant | 0.129*** | 0.00370 | -0.00153 | 0.264*** |
| | (0.0205) | (0.0276) | (0.0510) | (0.102) |
| Observations | 1,833 | 1,833 | 1,760 | 1,044 |
| R-squared | 0.003 | 0.025 | 0.035 | 0.068 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5. OLS Regression Models of Solution Novelty on Treatment Constraints

| | Dependent Variable: Solution Novelty | | | | Dependent Variable: Most Novel Solutions | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | Model 1 # constraints | Model 2 Rater FE | Model 3 Usefulness | Model 4 Controls | Model 5 # constraints | Model 6 Rater FE | Model 7 Usefulnes s | Model 8 Controls |
| # constraints | -0.152*** | -0.157*** | -0.157*** | -0.147*** | -0.0112 | -0.0108 | -0.0109 | -0.0104 |
| | (0.0451) | (0.0426) | (0.0427) | (0.0480) | (0.0104) | (0.00875) | (0.00876) | (0.0101) |
| Usefulness | | | -0.0153 | -0.0100 | | | 0.00874 | 0.0110 |
| | | | (0.0405) | (0.0419) | | | (0.00756) | (0.00793) |
| Constant | 5.089*** | 5.098*** | 5.188*** | 5.742*** | 0.263*** | 0.263*** | 0.211*** | 0.288*** |
| | (0.0768) | (0.0660) | (0.236) | (0.379) | (0.0185) | (0.0136) | (0.0455) | (0.0813) |
| Solver controls | N | N | N | Y | N | N | N | Y |
| Rater FE | N | Y | Y | Y | N | Y | Y | Y |
| Observations | 2,473 | 2,473 | 2,473 | 2,312 | 2,473 | 2,473 | 2,473 | 2,312 |
| R-squared | 0.005 | 0.007 | 0.007 | 0.018 | 0.000 | 0.001 | 0.001 | 0.013 |
| # of raters | 435 | 435 | 435 | 435 | 435 | 435 | 435 | 435 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 6. OLS Regression Models of Solution Usefulness on Treatment Constraints

| | Dependent Variable: Solution Usefulness | | | | Dependent Variable: Most Useful Solutions | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | Model 1 # constraints | Model 2 Rater FE | Model 3 Novelty | Model 4 Controls | Model 5 # constraints | Model 6 Rater FE | Model 7 Novelty | Model 8 Controls |
| # constraints | 0.0230 | 0.0138 | 0.0124 | 0.00303 | 0.0120 | 0.00823 | 0.00521 | -0.000159 |
| | (0.0348) | (0.0353) | (0.0351) | (0.0371) | (0.0123) | (0.0119) | (0.0118) | (0.0124) |
| Novelty | | | -0.00896 | -0.00598 | | | -0.0192*** | -0.0189*** |
| | | | (0.0236) | (0.0250) | | | (0.00664) | (0.00707) |
| Constant | 5.866*** | 5.880*** | 5.926*** | 5.851*** | 0.457*** | 0.462*** | 0.560*** | 0.605*** |
| | (0.0605) | (0.0546) | (0.128) | (0.273) | (0.0215) | (0.0185) | (0.0376) | (0.0858) |
| Solver controls | N | N | N | Y | N | N | N | Y |
| Rater FE | N | Y | Y | Y | N | Y | Y | Y |
| Observations | 2,473 | 2,473 | 2,473 | 2,312 | 2,473 | 2,473 | 2,473 | 2,312 |
| R-squared | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 | 0.000 | 0.006 | 0.015 |
| # of raters | 435 | 435 | 435 | 435 | 435 | 435 | 435 | 435 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 7. OLS Regression Models of Solution Creativity on Treatment Constraints and Constraints$^2$

| | Dependent Variable: Solution Creativity | | | Dependent Variable: Most Creative Solutions | | |
|---|---|---|---|---|---|---|
| VARIABLES | Model 1 # constraints | Model 2 Rater FE | Model 3 Controls | Model 4 # constraints | Model 5 Evaluator FE | Model 6 Controls |
| # constraints | 0.237 | 0.0752 | 0.0963 | 0.0616** | 0.0431 | 0.0505* |
| | (0.186) | (0.162) | (0.179) | (0.0281) | (0.0272) | (0.0291) |
| # constraints$^2$ | -0.116** | -0.0692 | -0.0774 | -0.0204** | -0.0140* | -0.0159* |
| | (0.0583) | (0.0520) | (0.0588) | (0.00859) | (0.00799) | (0.00876) |
| Constant | 10.74*** | 10.85*** | 11.35*** | 0.129*** | 0.138*** | 0.193*** |
| | (0.136) | (0.112) | (0.365) | (0.0210) | (0.0203) | (0.0572) |
| Controls | N | N | Y | N | N | Y |
| Rater FE | N | Y | Y | N | Y | Y |
| Observations | 2,473 | 2,473 | 2,312 | 2,473 | 2,473 | 2,312 |
| R-squared | 0.001 | 0.003 | 0.010 | 0.001 | 0.002 | 0.007 |
| Number of raters | 435 | 435 | 435 | 435 | 435 | 435 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Figure 1. Problem statement for control group and description of treatment constraints

**Base Problem Statement**

Now it's about your idea! We are searching concretely for your solution for a very specific and important customer concern:

**How to improve the wearing comfort of headphones?**

Please focus your idea on improving the wearing comfort of headphones, no matter what kind (in-ear/on-ear or over-the-head). Everyone can participate and every idea to improve wearing comfort is important.

***[Enter Treatment 1 here: Providing directions]***

For your solution there is only **one condition** to observe: Your idea must be inspired by your knowledge in areas **outside (!)** the world of headphones. So think: which solutions from other areas can you use for headphones and thus improve wearing comfort? Maybe you can draw on your professional and training experience to develop an idea? Or are your hobbies a great source of ideas? Recall events from your daily environment that could increase the wearing comfort when transferred to headphones!

That probably sounds unusual to you at first, but did you know that latest-generation swimsuits have the surface texture of shark skin? And your jogging shoes are made of the same materials that were previously developed for the shock absorption of racing cars. Teflon was first used in space travel before anyone had the idea of coating frying pans with it.

***[Enter Treatment 2 here: Limiting solutions]***

What happens to your idea afterwards? We will immediately forward your idea to ***[Enter Treatment 3 here: Evaluator type]*** will judge your idea according to their criteria. So your idea can be the basis for the development of the next headphones.
Take as much time as you like to develop your idea and then fill in the three questions below about your solution.

**Treatments**

**Treatment 1:** Providing directions

**Wearing comfort means** that the headphones must sit comfortably, i.e. they won't itch or squeeze even after a long period of time, but at the same time provide a firm hold without annoying slipping. Whether jogging or in front of the game console, sweating in summer or in winter with a cap, whether for big ears or small heads, with a storm hairstyle or with glasses, the headphones exactly meet your needs.

**Treatment 2**: Limiting solutions

Of course, your idea must also be realizable and **technically doable**. At Philips we have great engineers to implement your idea, but they are not magicians either. Therefore, pay close attention that your solution to improve wearing comfort can be implemented with the technologies you know and can actually be developed by us!

**Treatment 3:** Evaluation by community (non-experts) or experts

... **other members of the sound community for evaluation**. The community...

... **our [Company] specialists for evaluation**. Our [Company] specialists....

Figure 2. Estimated relationship between probability of solution generation and number of treatment constraints with 95% CIs

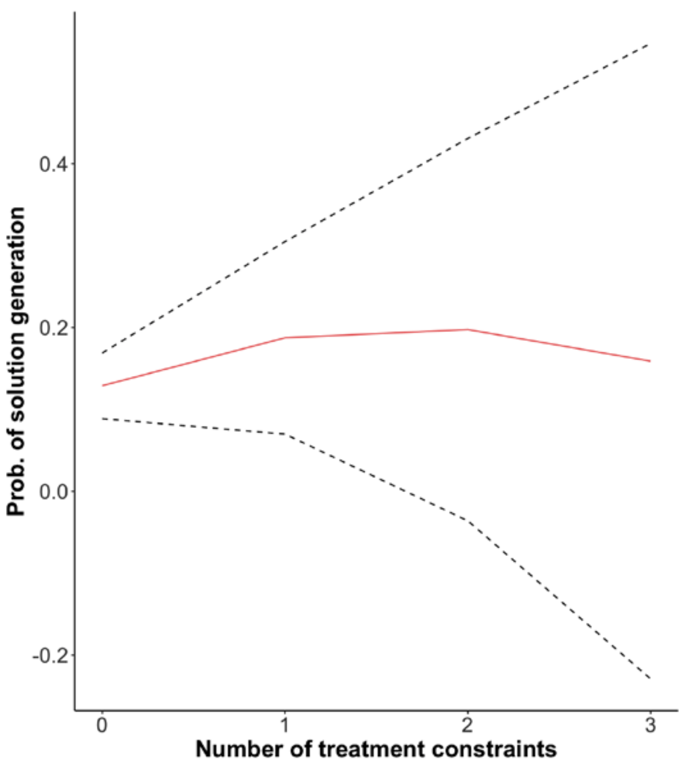


Figure 3. Margins plot for solution novelty and number of constraint treatments with 95% CIs

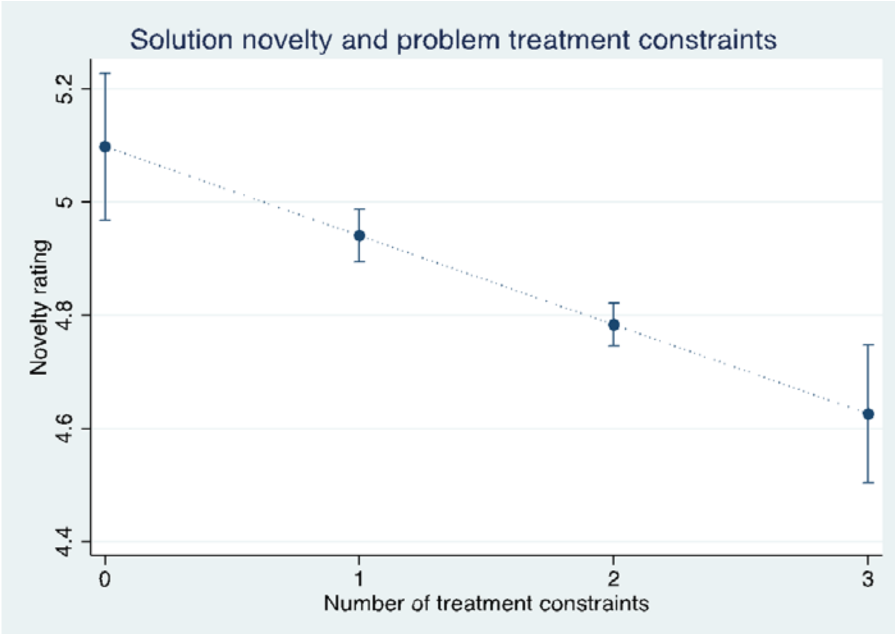
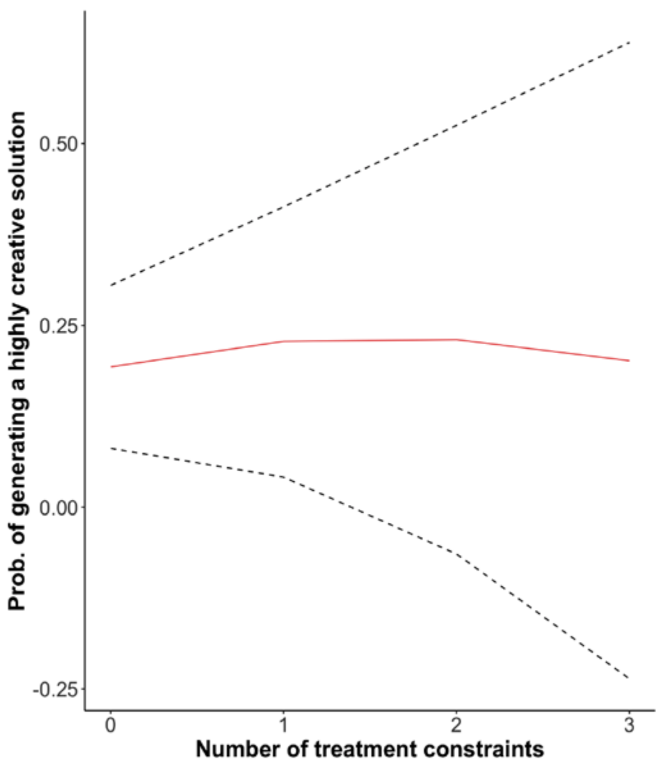



Figure 4. Estimated relationship between probability of generating one of the most creative solutions on the number of treatment constraints



## Appendix

Table A1. Number of Treatment Constraint Exposures by Constraint Type and Percentage Proposing a Solution

| Condition | # of treatment constraints | N | Prob(generating solution) |
|---|---|---|---|
| Control | 0 | 229 | 0.118 |
| T1: Providing directions | 1 | 229 | 0.164 |
| T2: Limiting solutions | 1 | 229 | 0.214 |
| T3: Community evaluation | 1 | 229 | 0.214 |
| T4: Providing directions & Limiting solutions | 2 | 229 | 0.214 |
| T5: Providing directions & Community evaluation | 2 | 227 | 0.154 |
| T6: Limiting solutions & Community evaluation | 2 | 226 | 0.190 |
| T7: Providing directions, Limiting solutions & Community evaluation | 3 | 229 | 0.170 |

Table A2. OLS Regression Models of Solution Novelty on Treatment Constraints and Constraints$^2$

| | Dependent Variable: Solution Novelty | | | Dependent Variable: Most Novel Solutions | | |
|---|---|---|---|---|---|---|
| VARIABLES | Model 1 # constraints | Model 2 Rater FE | Model 3 Controls | Model 4 # constraints | Model 5 Rater FE | Model 6 Controls |
| # constraints | 0.127 | 0.0311 | 0.00150 | 0.0420 | 0.0166 | 0.0174 |
| | (0.145) | (0.122) | (0.129) | (0.0342) | (0.0296) | (0.0315) |
| # constraints$^2$ | -0.0884* | -0.0596 | -0.0480 | -0.0169 | -0.00865 | -0.00898 |
| | (0.0451) | (0.0386) | (0.0418) | (0.0104) | (0.00907) | (0.00998) |
| Constant | 4.928*** | 4.989*** | 5.590*** | 0.232*** | 0.247*** | 0.334*** |
| | (0.106) | (0.0873) | (0.297) | (0.0259) | (0.0210) | (0.0654) |
| Controls | N | N | Y | N | N | Y |
| Rater FE | N | Y | Y | N | Y | Y |
| Observations | 2,473 | 2,473 | 2,312 | 2,473 | 2,473 | 2,312 |
| R-squared | 0.006 | 0.008 | 0.019 | 0.001 | 0.001 | 0.012 |
| Number of raters | | 435 | 435 | | 435 | 435 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A3. OLS Regression Models of Solution Feasibility on Treatment Constraints and Constraints$^2$

| | Dependent Variable: Solution Feasibility | | | Dependent Variable: Most Feasible Solutions | | |
|---|---|---|---|---|---|---|
| VARIABLES | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
| | # constraints | Rater FE | Controls | # constraints | Rater FE | Controls |
| # constraints | 0.110 | 0.0441 | 0.0948 | 0.0385 | -0.00589 | 0.0166 |
| | (0.112) | (0.118) | (0.125) | (0.0412) | (0.0372) | (0.0393) |
| # constraints$^2$ | -0.0277 | -0.00957 | -0.0294 | -0.00841 | 0.00447 | -0.00452 |
| | (0.0349) | (0.0371) | (0.0402) | (0.0125) | (0.0112) | (0.0124) |
| Constant | 5.815*** | 5.862*** | 5.760*** | 0.441*** | 0.471*** | 0.488*** |
| | (0.0840) | (0.0810) | (0.242) | (0.0312) | (0.0275) | (0.0782) |
| Controls | N | N | Y | N | N | Y |
| Rater FE | N | Y | Y | N | Y | Y |
| Observations | 2,473 | 2,473 | 2,312 | 2,473 | 2,473 | 2,312 |
| R-squared | 0.000 | 0.000 | 0.008 | 0.001 | 0.000 | 0.010 |
| Number of raters | 435 | 435 | 435 | 435 | 435 | 435 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1