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Marginality and Problem Solving Effectiveness in Broadcast Search

Lars Bo Jeppesen[1] **& Karim R. Lakhani**[2]

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Abstract

We examine who the winners are in science problem solving contests characterized by open broadcast of problem information, self-selection of external solvers to discrete problems from the laboratories of large R&D intensive companies and blind review of solution submissions. Analyzing a unique dataset of 166 science challenges involving over 12,000 scientists revealed that technical and social marginality, being a source of different perspectives and heuristics, plays an important role in explaining individual success in problem solving. The provision of a winning solution was positively related to increasing distance between the solver's field of technical expertise and the focal field of the problem. Female solvers – known to be in the "outer circle" of the scientific establishment - performed significantly better than men in developing successful solutions. Our findings contribute to the emerging literature on open and distributed innovation by demonstrating the value of openness, at least narrowly defined by disclosing problems, in removing barriers to entry to non-obvious individuals. We also contribute to the knowledge-based theory of the firm by showing the effectiveness of a market-mechanism to draw out knowledge from diverse external sources to solve internal problems

Key Words: Open Innovation, Problem Solving, Marginality, Gender, Broadcast Search

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[1] Copenhagen Business School
[2] Harvard Business School

Section 1 Introduction

An emerging perspective on the knowledge-based theory of the firm has argued that problem-solving effectiveness is key to superior organizational performance (Nickerson and Zenger 2004; Nonaka 1994; Nonaka and von Krogh, 2009). Managers inside firms have to both select high value problems to be solved, and, depending on the decomposability of those problems, choose to have them solved through internal hierarchies or external markets (Nickerson and Zenger 2004). While a bulk of the problems firms face may be solved through a combination of internal experienced-based local (March 1991), cognitive (Gavetti and Levinthal 2000) and analogical (Gavetti et al. 2005) search processes, there may still remain some problems that for a variety of reasons (lack of appropriate knowledge, lack of capacity, need for novel ideas) cannot be solved internally and need to be sent outside.

Faced with this situation, some firms may choose to eschew ex-ante contracts with preferred suppliers (outsourcing to firms, working with well-known academic consultants) (Taylor 1995) and instead initiate what we call a "broadcast search" problem solving process by disclosing the details of the problem at hand and inviting the participation of anyone who deems themselves qualified to solve the problem. Upon learning of the existence of the problem, solvers self-select to attempt to create a solution and are rewarded for their efforts if they are successful. In this paper we study the use of markets to solve internal firm-based research and development (R&D) problems and examine which external solvers are able to come up with successful solutions when all are invited to participate through a broadcast search process.

The role broadcast search can play in problem solving is perhaps best illustrated by the historical example of finding a practical method for determining longitude at sea. Solving the "longitude problem" was one of the greatest economic, scientific, and strategic challenges facing

most European nations from the 13th to the 18th centuries (Andrewes 1996). So great was the need to determine longitude at sea that in 1714 an act of the British Parliament established a prize of as much as £20,000 to be awarded to anyone who put forth a reliable method of doing so. The act defined the range of acceptable solutions (1, 2/3 and ½ degree accuracies) and established the Board of Longitude to evaluate and select a winner from among the proposed solutions. Sir Isaac Newton, the principal scientific advisor on the Longitude Board, had boldly asserted that only astronomical solutions were possible and were anyway to be preferred (Andrewes 1996). The prize elicited a tremendous number of solutions derived by a multiplicity of approaches from individuals with diverse backgrounds. Contrary to Newton's prediction, the ultimate practical solution was based not on astronomy but on clockwork. Developed by an unknown carpenter and clockmaker, John Harrison of Yorkshire, England, the solution was innovative on two counts: (1) it did not rely on astronomy, and (2) the design of the chronograph differed markedly from those developed by leading clockmakers, evidencing a novel understanding of materials science and mechanics (Randall 1996).

The longitude episode shows the effectiveness of the broadcast search problem solving approach and also foreshadows that unexpected individuals – that is, those on the margins – can develop solutions to problems when there is an open invitation to participate. Here we explore a modern version of broadcast search through an empirical investigation of firms' use of open research tournaments (Terwiesch and Xu 2008) and the awarding of prizes to obtain solutions to R&D problems that they had been unable to solve despite protracted efforts by internal R&D staff. While the extant economics literature on research tournaments (see for example: Che and Gale 2003; Fulllerton and McAfee 1999) has primarily focused on tournament design, incentives to participate, award size, entry criteria and the optimal size of the solver pool, there has been no examination of what determines whether individuals win or lose in these tournaments.

Our primary research question investigates which external solvers are able to come up with successful solutions when problem information is disclosed widely and contest entry is unconstrained. It could be that solvers who have deep knowledge and experience in the problem domain and consider themselves "close" to the problem may be most effective at broadcast search. Since problem solving overwhelmingly involves the use of prior knowledge and experience (Lovett and Anderson 1996), only those individuals that are core to the problem at hand will be successful in creating viable solutions. Hence broadcast search may be viewed as a way to find access to previously unknown "core" problem domain experts and augment traditional knowledge search mechanisms in the firm such as gatekeepers (Allen 1970) and absorptive capacity (Cohen and Levinthal 1990).

Alternatively, the public disclosure of the problem may expose it to individuals who are "marginal" and possess alternative knowledge or approaches that may be amenable to an effective solution. In this case, marginality becomes an asset because the individuals are not burdened by prior assumptions about effective problem solving approaches. Instead, they approach the problem with different perspectives and heuristics and create a novel solution. We posit two distinct ways of being marginal in problem solving, namely (a) technical marginality - being distant in terms of technical expertise from the field of the problem, i.e. in a different technical field, and (b) social marginality - being distant from the "establishment" in one's own professional community. Given a sizeable collection of external solvers, one or a few of these different perspectives or approaches may be relevant to effective problem resolution. Assuming that this claim holds, broadcast search can be considered a complement to the existing portfolio of search strategies used by organizations because it provides access to marginal individuals, who are "under the radar," that is, who possess alternative knowledge and approaches to the problems that are not within the normal purview of the problem domain.

Our analysis of 166 science problems, originating from the R&D labs of 26 firms in 10 countries and broadcast to a network of up to 80,000 scientists reveals that marginality of external solvers is a statistically significant predictor of problem solving success. By analyzing data on over 12,000 scientists that expressed interest in solving broadcast problems and carrying out a survey of those that submitted solutions to the problems we specifically find that both technical marginality, i.e. a solver's self-assessed technical expertise distance from the problem field; and social marginality, i.e. as proxied by being a female scientist-solver (as women have been shown to be in the "outer circle" of the sciences (Zuckerman 1991, Etzkowitz et al 2000)), relate independently to successful problem resolution. Access to diverse knowledge sources and approaches as embodied in marginal individuals is thus an operative mechanism of success in a broadcast search problem solving approach. Our findings contribute to the emerging literature on open and distributed innovation by highlighting the importance of marginal participants in solving problems, demonstrating the value of openness, at least narrowly defined by disclosing problems, in removing barriers to entry to non-obvious individuals. We also contribute to the knowledge-based theory of the firm by showing the effectiveness of a market-mechanism to draw out knowledge from diverse external sources to solve internal problems that have clear solution criteria but significant uncertainty about the most appropriate solution approach.

The rest of the paper is organized as follows. In Section 2, we discuss what types of problems can be solved using markets. In Section 3, we discuss the marginality advantage in broadcast search problem solving and generate our hypotheses for analysis. In Section 4, we provide the empirical context of our study and the data in our analysis. Section 5 provides details of our estimation strategy and Section 6 contains data on the population and sample of problems and solvers in our analysis. Section 7 has our findings, robustness indications and potential limitations. In Section 8, we discuss our findings and draw conclusions.

Section 2 Problem Solving in Markets

At its most basic level, a problem occurs when an individual, team or organization has a "goal to achieve and does not know immediately how to achieve it" (Baron 1988; p. 49). Problem solving is thus "any goal-directed sequence of cognitive operations directed at finding that unknown" (Jonassen 2004; p. 7) that is, essentially a search for the solution to reach the goal. Problems themselves can range from being ill-structured, i.e. poorly defined initial states or indefinite problem solving spaces, to well-structured, i.e. well-defined initial states and known elements, explicit approaches for solving and known criteria for solutions (Simon 1973). The structure of the problem is important as it determines the level to which it can be decomposed into smaller components so that specialist solvers can use their expert knowledge to solve subparts of the larger problem independently. Ill-structured problems cannot be decomposed due to the unexpected and unknown interactions among the potential different knowledge sets that make up the overall problems and the lack of definitive criteria for assessment of solutions (Jonassen 2004; Levinthal 1997; Simon 1973). Well-structured problems, by contrast, can be addressed by decomposition because all of the potential knowledge set interactions implicated in the solution are known and understood. This demarcation, however is not always fixed and clear; most problems in real life are what Simon (1973) describes as "nearly well structured," i.e. ill-structured problems that have been formalized and transformed to such an extent that the overall problem can be decomposed into sub-problems. Experts are then assigned to find solutions to the sub-problems that can subsequently be integrated and combined to form the whole solution

The degree of problem decomposability is the insight which Nickerson and Zenger (2004) use to determine whether external markets or internal hierarchies[3] are best suited to solving internal firm problems. They propose that the more decomposable a problem, the more amenable it is to a market-based problem solving approach because a clear solution criterion has been identified. Note, however, that, as Simon (1973) observes, problem decomposability does not mean that the sub-problems being parsed out for expert solution are themselves necessarily well-structured or even easy to solve. Problem decomposability simply means that a suitable modularity of the problem space (Baldwin and Clark 2000) has been achieved, i.e. the interactions amongst the sub-problems have been identified and understood, but there may still be a high degree of uncertainty and difficulty in developing the actual solution to any specific sub-problem. Hence the sine qua non of using markets to solve problems is a clear articulation of the problem (or sub-problem) and the development of a solution criteria, for example, a method to find longitude at sea within the specified degree range.

Most external innovation-related problem solving by firms involves the use of bilateral contracts between the problem holder and problem solver (Taylor 1995). However, the uncertain nature of the research enterprise in general and the difficulty of monitoring effort when inputs are unobservable in particular (Holmström 1989), sometimes undermine the case for ex-ante contracts for R&D effort (Mowery and Rosenberg 1989). An alternative market-mechanism to solve problems is the use of a research tournament where an award is given when a solution to a problem has been developed and verified (Taylor 1995). The academic literature on research tournaments has primarily focused on the logic of benefits to the problem holder (solution seeker), tournament design, maximization of social welfare, award structure, entry criteria, optimal

[3] An internal hierarchy is simply a firm-like structure where managers allocate resources, tasks and personnel. The actual problem solving effort inside the firm will of course vary and can include teams of peers or strict hierarchical reporting relationships.

solver pool size, the means to induce effort amongst solvers, and the tradeoffs between internal and external development (Boudreau et al 2009; Che and Gale 2003; Fullerton and McAfee 1999; Taylor 1995; Terwiesch and Xu 2008). However, the question that has not been asked or answered in the literature is what determines who will be a successful solver when the problem is broadcast and anyone can participate?

Section 3 The Advantage of Marginality

On the surface it would appear that a successful solution to a broadcast chemical engineering problem is most likely to be developed by a chemist instead of a biologist (Terwiesch and Xu 2008). This view that those that have experience and knowledge in the problem domain and are close to the problem are most likely to develop successful solutions is backed up by research that indicates that problem solvers, at the individual, team, and organizational levels, overwhelmingly use prior experience and knowledge in solution development and often encounter difficulty in solving novel problems (Allen 1970; Duncker 1945; Lovett and Anderson 1996; Luchins 1942; Sorensen and Stuart 2000). Hence biologists or physicists may be ill-suited to create successful solutions to chemistry problems. However, this perspective assumes that problems are fixed and defined by the field they emerge from.

Problem solving involves the construction of an internal representation of the problem, a perspective, and the simultaneous application of an appropriate algorithm, a heuristic, to search for the solution (Dunbar 1998; Hong and Page 2004). Thus a perspective-heuristic pair defines both the problem/solution landscape and the method of traversing through the hills and valleys of that landscape in search of a high value solution (Baron 1988; Cyert and March 1963; Newell and Simon 1972; Simon 1969). The idea that differences in perspectives and heuristics may be the source of problem resolution has been explored at the intersection of problem solving, economics and the behavioral theory of the firm literatures (Dosi et al. 2003; Marengo et al. 2000; Newell and

Simon 1972; Page 2007). A key insight is that the choice of a perspective contributes to a problem's difficulty (Marengo et al. 2000; Page 2007) and, thus, in instances of a problem that appeared novel, difficult and even unsolvable to some, alternative perspectives of other problem solvers may yield an effective solution. Hence problem solvability often depends on the eye of the beholder.

The following example from Page (2007; p.32) helps to illustrate this conjecture. In mathematics, objects in Euclidean space can be represented by either a Cartesian or a polar coordinates system representing two potential perspectives on the same issue. Describing a rectangle is fairly simple in a Cartesian system, but quite complex and convoluted in the polar system. Conversely, a circle is trivially defined by a radius and an angle in the polar system, but rather more difficult to define on the Cartesian plane. A problem solver not versed in polar coordinates will have an extremely difficult if not impossible task of mathematically describing a circle using just the Cartesian system and vice versa. Different perspectives exist because they help us solve particular sub-problems in the larger problem domain, indeed, some have argued that finding alternative perspectives may be an "even more powerful problem-solving strategy than decomposition" (Marengo et al. 2000: p.765). Importantly, this implies that a problem solver's perspective can actually define the problem/solution landscape and its ruggedness.

Once a perspective on a problem is set, the problem solver then employs heuristics to actually find the solution. Heuristics are the rules or algorithms of search that tell the problem solvers the specific actions that need to be taken and the potential ways of finding the best solutions (Dunbar 1998). Just as there is variance in perspectives amongst problem solvers, there is similar variance in the heuristics deployed by problem solvers. Hong and Page (2001, 2004) have used analytical models and simulation analysis to show that the formulation of different

search heuristics from the same perspective yields solutions of unequal value, implying that differences in heuristics can also influence problem solving success.

Taking a perspective-heuristic view on problem-solving allows us to reinterpret the conjecture that only chemists or chemical engineers are better suited than individuals from other domains to solve a chemical engineering problem. Recently, as described in Howe (2008: p.150), a firm faced a particularly intractable chemical engineering problem that had stymied progress for a significant period of time. The ultimate solution came from an external physicist who applied principles of electromagnetism to what was thought to be a chemistry problem.

Problem solving through the systematic use of diverse perspectives and heuristics implies that successful solvers may not necessarily be affiliated with the problem field. This view is supported by studies in the sociology of science literature that have shown that "inventions are usually made by outsiders, that is, by men who are not engaged in the occupation which is affected by them and are, therefore, not bound by professional customs and traditions" (Ben-David 1960: p.557), i.e. marginal individuals. Empirically focused studies within the fields of medicine (Ben-David 1960), molecular biology (Mullins 1972), and protein crystallography (Law 1973) found that scientists responsible for major innovations in a field tended to be marginal to that field (Chubin 1976). However, marginality need not be responsible for big scientific breakthroughs only; it can also operate within disciplines and be helpful in solving micro-issues and "smaller" problems (Dogan and Pahre 1990).

The literature has identified two major processes by which individuals arrive at marginal positions; the first relates to being in different technical fields and the second relates to social attributes (age, institutional affiliation, education pedigree)(Gieryn and Hirsh 1983; McLaughlin 2001). While there is a debate about the appropriate measurement of marginality and its potential impact in scientific problem solving (see for example the exchange between Gieryn and Hirsh

(1983, 1984), Handberg (1984) and Simonton (1984)), the main theoretical mechanism underlying the marginality effect is based on individuals having access to differing knowledge and perspectives than the actors in the source problem field. Marginal individuals have a so-called "focused naïveté: a useful ignorance of prevailing assumptions and theories," (Gieryn and Hirsh 1983: p. 91) that allows them to attempt to create potentially novel solutions to problems.

Our overall argument is that marginal solvers are not bound to the current thinking in the field of the focal problem and therefore can offer perspectives and heuristics that are novel and thus useful for generating solutions to these problems. Though there are significant disadvantages to being marginal in a social context, such as the limited access to relevant problem information, lack of resources, and isolation; a potential advantage of marginality in the context of broadcast search. Although a different perspective may be crucial to problem resolution, it is not necessarily a sufficient condition to bring about a desired solution. Any given new perspective is not likely to be useful for solving a difficult problem: what matters is to be different and relevant (Page 2007). Therefore, the odds that any given solver will be able to solve a specific problem are quite low; other things being equal, those odds increase with each additional solver who arrives with a different analytical toolkit and perception of, and angle on, the problem. This is precisely the mechanism behind broadcast search with an open call for participation.

We focus here on the two types of marginality that can lead to less conventional heuristics and perspectives on a problem and that are directly applicable in our context of broadcast search: first, being technically distant from the field of the problem, i.e. in a different problem field, and, second, being socially distant from the core establishment, i.e. being socially excluded from the field. We first consider being technically distant from the field of the problem. Due to the fact that they are not closely affiliated with the problem field, marginal individuals are well positioned to possess perspectives and heuristics that are not present in the focal field context. Further, as

new perspectives on a problem can come from outside a given professional field (Fernandes and Simon 1999), we argue that technical marginality may be conducive to successful solutions in a broadcast search context.

In a setting where there is no a priori selection and screening of potential solvers and anyone can participate, marginal individuals may be able to access previously inaccessible problems and self-select to employ their different (and potentially relevant) perspective on a given problem to create high performing and successful solutions. In sum, we propose that:

H1: *Successful solution generation in a broadcast search context will be positively associated with increasing distance between the solvers' field of expertise and the focal field of the problem, i.e. technical marginality.*

The second type of marginality we consider arises from the adverse circumstances of individuals being involuntarily pushed out or denied access to the core establishment of a scientific field. While factors such as institutional affiliation, degree pedigree and age have been found to have mixed results in both predicting marginality and achievement, one factor that has found considerable empirical support as it relates to social exclusion is gender. Notwithstanding the expressed intention that careers in science be "open" to talent (Merton 1942), there is strong evidence of systematic social exclusion and marginality of women in the natural sciences (Etzkovitz et al. 2000). Studies have shown that this exclusion is primarily based on the functional criterion of gender and not on innate scientific ability or lack of career commitment (see Zuckerman 1991 for an extensive review of studies). Across the sciences, women's career persistence and mobility post degree fall well below their doctoral attainment levels (Xie and Shauman 1998, Ding, Murray and Stuart 2006). Studies of causes of productivity differences between the sexes, the "productivity puzzle," attribute the observed gap not to self-selection reasons like marriage and motherhood or some combination thereof (Cole and Zuckerman 1984) but to the marginal positions into which many women are shunted (Xie and Shauman 1998).

Therefore, notwithstanding their considerable talent, women are, on the whole, more likely to be in the "the outer circle" of the scientific establishment (Zuckerman et al 1991) coping with "social exclusion in an activity that necessitates, perhaps demands, community" (Etkovitz et al. 2000, p. 16).

Because individuals become socialized to the norms and beliefs of their fields and organizations, remaining at the margins while keeping up to date and actively pursuing access to resources offers those marginalized a different set of perspectives and heuristics than those at the core of the professional establishment (McLaughlin 2001). This allows them to view and approach problems in a more unconventional way; a factor that might be crucial to the production of novel solutions. Potentially productive marginalized solvers, who are to a large extent highly trained and talented individuals who could not enter core positions in their fields, read "women scientists," might be more capable of approaching problems in fresh ways, one of which is likely to uniquely match a given problem. Here the "forced" social marginality of women in science, in effect an exclusion from the thought worlds (Dougherty 1992) of their own scientific fields, may provide a fleeting advantage in an overwhelmingly disadvantaged social position.

Further, the social exclusion process drives two related effects of relevance to broadcast search. First, the experience of social exclusion built up during the course of a scientific career causes women scientists to be more cautious and reserved and generally to hold back from publicly disclosing ill-supported hypotheses until they are very certain about the expected outcome (Etzkovitz et al. 2000). This implies that women as a whole may participate less, but when they participate, the quality of their submission is higher. Second, the social exclusion of women also means that there is a pool of untapped talent (women) available to participate in broadcast search. Similarly talented males are likely to be laboring within science organizations and are as a whole

less likely to be motivated to participate in broadcast search activities. This leads to our second hypothesis:

H2: Successful solution generation in a broadcast search context will be positively associated with being a woman, i.e. social marginality.

Section 4 Empirical Context

We assess the impact of marginality on problem solving success by analyzing a unique dataset of science problem solving contests at InnoCentive.com (IC), a spinout from Eli Lilly and Company's internet incubator, launched in June 2001. IC is designed as a two-sided platform where individual scientists, "solvers," enter contests to compete against one another in order to solve science problems, "challenges," broadcast by IC's clients, the "seekers." Successful solvers receive a pre-announced cash prize for creating the winning solution. Seekers come from diverse industries including aerospace, agrochemicals, biotechnology, chemicals, consumer products, and pharmaceuticals. Most of the problems had been attempted to be solved by internal scientists of the originating R&D lab of the seeker firms, which in some instances expended several years of unsuccessful effort on solution generation.

The starting point for an IC challenge is defining the problem that needs to be resolved. Internal scientists from the seeker firms work with IC's scientific operations staff (program managers) to articulate a problem statement that is accessible to a wide range of external scientists and to determine the appropriate level of prize money for the successful resolution of the problem. This results in the creation of a two to three page challenge statement, which provides details on the problem and the solution criteria that will be used to judge success, the time window in which solutions will be accepted, the disclosure of the prize award and the categorization of the challenge under appropriate scientific disciplines from a potential list of up to 60 areas. IC began building its solver base when it was launched in June 2001 and expanded it to over 80,000

individuals during the study period. IC grew its community of solvers through traditional marketing in science journals, academic conferences, favorable press coverage about their unique model, and by outreach to various scientific societies about the financial and intellectual benefits of solving science problems. IC does not do any pre-screening of solvers and anybody with internet access is able to go to the IC website and register as a potential solver. Registration simply requires the disclosure of minimal information including an email address, a full name and an indication of the scientific interests of the solver taken from the same list of 60 potential scientific disciplines of a challenge (see above). Solvers receive weekly emails outlining the new challenges posted on IC and can also view all open challenges on IC's website.

IC solvers do not work collectively, through the website, to solve problems and do not know who else is working on a problem or how many solutions have been submitted. Submitted solutions are screened, and those that meet all requirements are forwarded to the problem holder firm. Scientists at the originating R&D lab evaluate the submissions and inform IC if they find one that meets the solution criteria. The decision to award the prize money to the best solution rests with the problem holder firm, which can choose to make the award, or multiple awards, or not.

Problem holder firms and solvers remain anonymous to each other throughout the problem solving process and the winner selection by seekers is blind. Care is taken to protect the intellectual property (IP) rights of problem holders and solvers. Solvers initially see broadcasted problems in the form of an abstract of the problem definition. To see the full details of problem and requirements for its solution, they must first accept a solver agreement outlining the reward and review period, requirements for confidentiality, and intellectual property transfer clauses for accepted solutions. Solvers issue problem holder firms a temporary license to evaluate submitted solutions. If a solution is deemed acceptable, the solver receives the pre-announced award prize and transfers all IP rights to the problem holder firm. Before effecting the transfer, IC contacts

the solvers' employer to ensure the release of any and all IP claims on the solution. Problem holder firms relinquish all rights to use information provided in submitted solutions that are not accepted. Enforcement is provided for by contracts that grant IC the right to audit the output of problem holder firms' laboratories.

Data Sources

The broadcast search process at IC can be described as a four step process involving: 1) the seeker firm establishing the problem statement and the award value and then broadcasting the problem abstract to the entire solver base; 2) solvers self-selecting to make the decision to learn more about the problem by downloading the full problem statement and agreeing to the contest terms; 3) a subset of these solvers working on the problem and then submitting a solution for evaluation; 4) the seeker firm deciding whether none, one or more of the solutions meet their criteria and declaring the problem to be solved or not solved. During our study period, 166 problems were broadcast on IC to a solver population of up to 80,000 individuals. The broadcast of these problems triggered 14,659 individuals to download one or more problem statements for further examination. Out of this population, 993 individuals decided to actually submit solutions to one or more problems and firms declared 49 of those problems solved by awarding prizes to 75 submissions from 59 solvers.

The two main sources of data in our study were (1) problem and solver information stored in IC's database and, (2) an online survey sent to the 993 individuals that had submitted solutions to IC problems. Problem data furnished by IC included challenge solution format, i.e., a reduction to practice (RTP) (e.g., "An enzyme stabilizer at high pH is required") or a "Paper/Theory" (e.g., "Can you formulate a simple, stable, and safe injectable suspension placebo that has no pharmacological and biological activity) submission requirement, monetary prize award size, the primary scientific discipline of the challenge, and whether or not the awards were given to

solutions and thus if problem was deemed solved, partially solved or not solved by the seeker. Solver data from IC included information on the specific challenges that were downloaded by the solver, the number of solution submissions made, and whether the solver had been successful in creating a winning solution. We also received information on the scientific interests of the solver and their name.

We also collected information about the population of solvers who had submitted solutions to IC problems by requesting their participation in a 20-minute, online, web-based survey (administered with the cooperation of IC). The survey asked for information about their degree of knowledge of the problem, the effort they put into creating the solution, their motivation for participating in a contest and exerting effort without a guarantee of reward, and demographic information including gender, country and educational achievement. We pre-tested the survey with two current IC solvers, three individuals with PhD's in scientific fields (to represent potential IC solvers without reducing our potential sample) and with five members of IC's scientific operations staff to ensure that the questions were clear and unambiguous.

The solvers received customized e-mails from IC's chief scientific officer requesting that they respond to the survey. They were reminded of a specific problem for which they had previously attempted to solve and the date of their submission to IC. Solvers who had created submissions to multiple problems were asked about their most recent submission. Those who had been successful in at least one attempt were asked to respond to the survey with regard to their most recent winning submission. In all cases the solvers in our sample received the abstract of the problem we wanted them to focus on and a web link that provided them with problem statement and their relevant submission. Tests for sample representativeness are reported in Section 6.

Section 5 Estimation Strategy

As discussed above, the broadcast search process relies on the self-selection of solvers to request details of the problem statement and then also to choose to submit a solution. Thus participation in an IC broadcast search problem solving process does not occur randomly but is instead predicated on endogenous choices made by individual solvers. Therefore, any regression analysis that does not take into account the self-selection decisions of individuals will result in biased coefficient estimates due to omitted variables that affect both the decision to participate and the resulting outcome (Hamilton and Nickerson 2003).

To control for sample selection bias we used a Heckman-Probit model. This two-stage endogenous self-selection model allows for the correction for this bias and is appropriate in contexts where individuals make a discrete choice to participate, after which their performance outcomes are observed (Greene 2000). However, the original Heckman model assumes a binary choice for selection into the sample and a continuous outcome for the main dependent variable (Heckman 1979). Given that the IC context consists of two binary outcomes: 1) choosing to submit a solution and 2) being selected a winner, the traditional Heckman model will not be appropriate; instead, we use a probit model with sample selection correction as pioneered by Van de Ven and Van Praag (1981). This model is simply an extension of the Heckman model that takes into account the statistical properties of a two-stage discrete choice estimation. The first stage models the process of the selection into the sample, and the second stage models the discrete outcome and includes an error correction term obtained from the first stage estimation.

First Stage: Decision to Submit Solution

The first stage in our model examines the decision of IC solvers to exert effort and submit a solution for evaluation upon getting the details of a problem. The unit of analysis is the IC solver who has downloaded at least one problem statement. For those solvers that downloaded more than one problem statement, we examined the most recent problem that they downloaded

and accounted for their past actions by counting the previous numbers of problem statements they had opened. Solvers that submitted solutions to more than one problem were included in the data set on the basis of their most recent submission. Solvers that have won at least once were included on the basis of their most recent winning submission.

We model the IC solver's decision to exert effort and submit a solution, **Submit Solution**, as a function of the characteristics of the problem and the characteristics of the solver. Specifically we estimate the equation:

Prob(**Submit Solution** = 1) = β_0 +β_1**Award Value** + β_2**RTP Solution Requirement**+ β_3**Solver Interest Profile & Problem Discipline Match**+ β_4**Previous Problems Opened** + β_5**Gender** +β_6**Ethnicity** + ε (1)

The first two variables used in the first stage equation are **Award Value** and **RTP Solution Requirement**. Upon reading the problem statement, the IC solver has to judge whether the prize award (Award Value) is attractive and whether they have the capacity to develop the appropriate solution based on requirements (RTP Solution Requirement), i.e., a reduction to practice solution requirement will require access to equipment that may not be commonly available. In our analysis, Award Value is the log of the dollar prize award for the focal problem, and RTP Solution Requirement is a binary variable that takes on the value one if the solution requires a reduction to practice submission or the value zero if a paper/theory submission is requested.

The next variable, **Solver Interest Profile & Problem Discipline Match,** attempts to capture a solver's decision to self-select and submit a solution due to potential overlap between the solver's own scientific interest profile and the problem discipline. This variable takes on the value one if there is a match between the range of scientific interests previously expressed by the solver and the primary scientific discipline of the problem and zero otherwise.

The variable **Previous Problems Opened** keeps track of the number of prior problem statements a solver has opened. We include this variable because the propensity to submit a solution may also be impacted by the number of previous problem statements that a solver has opened in the past. Since there is no cost of opening and examining the contents of the problem statement, a solver may examine several statements before picking the one that seems appropriate for effort.

We include **Gender** as a variable impacting submission probability since recent economic experiments have highlighted that controlling for ability and given a choice between a competitive, i.e. winner-take-all payment, and a non-competitive, i.e. piece-rate payment, environment, women are less likely to choose to compete (Croson and Gneezy 2009; Niederle and Vesterlund 2007). Thus the gender of the participant may impact the likelihood of creating a submission.

IC's registration process does not ask solvers to identify their gender. In our online survey we did request and receive gender information from the solvers; however, this does not cover the vast majority of over 14,000 IC solvers that we observe downloading the problem statement and then making the choice to submit (or not) a solution to an IC contest. IC did furnish us with the full names (first and last) of solvers that had registered on its site and we used this information to help us determine the gender of the IC solvers. Specifically, we worked with the services group of IBM's Infosphere Global Name Recognition product team to use their Global Name Analytics program to identify the gender of IC solvers through their names. The Global Name Analytics program utilizes publicly available databases (for example names and gender obtained from driver's licenses) and proprietary databases (for example credit card databases) to create a gender propensity score (given as a percentage) for a given name. We only utilized values of 51% or higher to assign the gender to a solver's name. We also cross-verified the IBM results with our own gender information from the survey. The mismatch between IBM's automatic scoring and

our survey-based name collection was only 2.6% and related to ambiguous names like "Pat," which could be used by a Patricia (female) or a Patrick (male). We corrected the IBM scoring to reflect our survey-based gender data and then created a variable (Gender) which took on the value one if the name was determined to be female and the value zero if the name was male.

Finally, another central demographic variable, **Ethnicity** was included in the analysis to create a proxy for country of residence of the solver. Lack of economic opportunities and the presence of US-dollar based prize awards may cause equivalently talented individuals to participate in IC contests at varying rates depending on their country of residence. Since IC had incomplete data on the country of residence for their solvers, we chose to use ethnicity instead. We once again utilized the IBM Name Analytics program to determine the ethnic composition of our solver population. The IBM program gave (16) ethnic composition classifications to the first, last and combined names of the solvers. If it could not determine the name origin it would classify it as "ambiguous." We assigned each solver an ethnic classification first on the basis of their full name, then their last name and then their first name. We created the dichotomous variable (Ethnicity) that took on the value of one when the ethnic classification for the solver was "Anglo Saxon" and zero otherwise. Note that out of the 14,649 names received we were able to resolve gender and ethnicity data on 12,786 solvers. The remaining solvers provided only initials for their first or last name and this prevented the IBM software from placing them in the appropriate category. This only occurred with individuals that had downloaded the problem statement but had not submitted a solution for evaluation. Hence our first stage data consist of 12,786 observations. Finally, β_0 is the constant and ε is the error term in our estimation.

Second Stage Model: Success in Broadcast Search Problem Solving

Conditional on submitting a solution for evaluation in an IC problem solving contest, the second stage in our model examines who becomes a winning solver. Our dependent variable,

Solver Winner, is binary and developed using data available from the IC database on whether a solver had won a prize or not for their submission. The variable was given a value of one if the solver had won and zero otherwise. Equation 2 shows the relationship we are trying to estimate:

Prob(**Solver Winner**=1) = β_0 + β_1 **Expertise Distance**+ β_2 **Gender** + β_3**Problem Familiarity+** β_4**Scientific Interest Count +**β_5**Solver Interest Profile& Problem Discipline Match +** β_6**Time Invested** + λ_{HP} + ε (2)

Our first independent variable is **Expertise Distance,** which captures the self-perceived distance between the problems solvers were attempting to solve and the solvers' own field of expertise (Handberg 1984) and relates to our first hypothesis. The variable is based on the answer to the following survey question: *"Is the particular challenge you attempted to solve: "1 – inside your field of expertise, 4 – at the boundary of your field of expertise, 7 – outside your field of expertise?"* Respondents could choose any value between 1 and 7 on a Likert scale. The higher the score, the greater the perceived distance between the solvers' field of expertise and the problem field. The variable tries to capture a sense of technical marginality between the solver and the field of the problem.

Our second independent variable, **Gender**, is derived from our second hypothesis in which we predict a positive impact of socially marginalized individuals in general and women in particular in solving the broadcast search problems from IC. This variable is the same as in the first stage model.

Our first control variable is **Problem Familiarity,** which is based on the response to the following question: *"When you first saw the particular InnoCentive Challenge, what was your experience with similar problems? 1 – This problem was completely new to me, 4 – I was somewhat familiar, 7 – I had seen the EXACT problem before."* Respondents could choose any value between 1 and 7 on a Likert scale.

The next control variable is **Scientific Interest Count**, which records the number of scientific interests of the solvers. A solver's success in creating a winning solution may also be

driven by an overall generalist or a specialist orientation towards science. The higher the number of scientific interests reported, the more generalist a solver's orientation.

The control variable **Solver Interest Profile & Problem Discipline Match** – also used in the first stage of the model - is then included to account for the possibility that success in creating the solution may also be impacted by the match between the solvers' interests and the primary scientific field of the problem. As a final control, the variable **Time Invested** is included to account for the solvers' effort. It is based on the survey question: *"How much time did it take you to develop your submission (please estimate hours of effort)?"*. Finally, note that λ_{HP} is the sample selection correction term obtained from the first stage model, $\beta_0$is the constant, and ε is the error term in our estimation model. Figure 1 summarizes the four-step model of broadcast search that drove our data collection and analysis strategy.

<Insert Figure 1 here>

Section 6 Population and Sample Characteristics

We first report on the overall performance of broadcast search and the population of individuals that downloaded problem statements for submissions, and then provide information on the details of our sample of solvers.

Problem Characteristics and Solver Population Overview

Of the 166 problems posted, 49 were deemed solved by the problem holder firms, yielding a solve rate of 29.5%. A majority (58%) of the problems stipulated "reduction to practice" submissions, the remainder, theoretical ("paper") submissions. A financial award was offered in connection with all problems (mean: $29,689, median: $25,000, range: $2000-105,000 US). Problem solutions had to be delivered within a specified time frame (mean: 166 days, median: 108

days, range: 14 to 554 days). Winning solutions arrived, on average, within 84 days (s.d.: 65.5 range: 2-262) of the problem posting.

On average, 240.7 (s.d.: 195.0, range: 19-1058) individuals examined the detailed problem statements and 9.9 (s.d.: 14.2, range: 0-103) submitted solutions. Problems that were solved received more than twice the number of submitted solutions (mean: 16.8, s.d.: 21.5) as unsolved problems (mean: 7.0, s.d.: 8.1) ($t=-4.2$, $p=0.000$). Seventy-one percent of the solved problems had a single "best" solution for which one solver was awarded the prize. The remaining 29% had multiple "best" solutions (range: 2-5), for which multiple prizes were awarded. In a few cases, problem holder firms were able to accept and combine independent solvers' partial, non-overlapping solutions into a full solution. In all, 75 winning submissions were received for 49 solved problems from 59 solvers. The data reveal the successful problem solvers to be widely distributed: 87.5% of winning solvers had one successful submission, 8% had two. Different individuals from two contract research labs were successful three and four times. Discussion with IC staff indicated that the solvers were different individuals in each case.

IC participants expressed interest in, on average, 9.9 scientific areas, had opened, on average, 2.7 prior problems statements, and 37.1% had a match between the scientific area of the latest problem statement and their own scientific interest profile. Individuals with Anglo-Saxon ethnicity comprised 28% of the IC problem statement downloader population. Women comprised 15.6% of the downloader group and 11.4% of the group that submitted solutions for assessment. Out of the 59 winning solvers, 9 (15.2%) were women.

Survey Sample Characteristics

Our survey to the 993 individuals that submitted at least one solution to IC resulted in 377 responses of which 320 were complete for our analysis thus yielding a relatively high response rate of 32.2% (Sheehan 2001). The 320 respondents represented 93 (56%) of the 166 broadcast

problems during the study period. Table 1-A presents the contrasts between the problems worked on by our survey respondents and the non-respondents. Overall, the problems in the respondents sample had lower average award value, were less likely to be RTP, had higher number of individuals express interest in solving them, more solution submissions and were more likely to be deemed solved than the problems that were not in the survey sample (analysis conducted using t-tests).

<insert Table 1 about here>

Table 1-B shows that the individual solvers in our survey sample did not have statistically significant differences (using t-tests) from non-responders in the population of all solvers who submitted solutions for key variables in the analysis including: Gender; Number of Scientific Interests; Solver Interest Profile & Problem Discipline Match; and Ethnicity. Respondents did have statistically significant differences from non-responders with regard to a higher number of Previous Problems Opened, less likely to be an RTP Solution Requirement problem and concomitantly lower Award Value.

We conducted several tests to check for potential bias in our data with regard to gender and winners in our sample. We assessed if the gender distribution of the survey respondents (288 males; 32 females) was similar to the non-respondent group (592 males; 81 females). Analysis of the two-way contingency table of gender and survey response resulted in a Fisher Exact value of 0.393 and the related Pearson Chi-Square value of 0.891 ($p = 0.345$) allowing us to comfortably claim that the gender distribution amongst the survey respondents was statistically similar to the survey non-respondents.

In all, 64.4% of the winning solvers and 30.1% of the non-winning solvers responded to our survey. Our survey sample included 39 winning solvers and 281 non-winning solvers; 7 women comprising 17.9% of the winning solver group responded to the survey. We once again

used a two-way contingency table to assess differences between the gender distribution amongst the winners in our survey sample (32 males, 7 females) and the non-respondent winners (18 males, 2 females). The analysis showed that there was no statistical difference in the gender distributions of winning non-respondents and respondents, the Fisher Exact value was 0.704 and the related Pearson Chi-Square value was 0.646 (p=0.421). Second, we ran a separate logistic regression predicting participation in the survey as the dependent variable. Our independent variables were the gender of the solver, solver winning outcome and an interaction term between gender and winning outcome. Over representation by winning women in the sample would be a concern if the interaction term was significant. Our analysis showed that p-value for the interaction term to be p = 0.329 – thus reducing concern about this variable. We cannot replicate this regression test for the Expertise Distance dimension because we do not have this variable from the non-responders. However we used the variable Solver Interest & Problem Discipline Match as a proxy in an additional similar logistic regression predicting participation in the survey. Our independent variables were solver interest/problem discipline match, winning outcome and the interaction between them. Over representation in the sample by those winning and not having a match between their own interests and the problem field would be a concern if the interaction term was significant. Our analysis showed that the p-value for the interaction to be p = 0.386 thus reducing concern about over representation by winners in the sample.

Solvers were highly qualified; 65% of solvers reported holding Ph.D. degrees, 19.1% advanced degrees. On average, solvers had completed their formal education 16 years (s.d.: 12.86) prior to responding to the survey, with no significant difference between Ph.D.s and non-Ph.D.s. Solvers in the sample reported, on average, 10.0 (s.d.: 11.3) areas of scientific interest, with no significant difference between winning solvers and non-winning solvers, and expended, on average, 42.7 hours (s.d.: 117.57) of their own time developing a solution (winning solvers

reported expending, on average, 111.75 hours (s.d.: 42.85), non-winning solvers 33.49 hours (s.d.:4.8) ($p<0.1\%$)).

The majority of solvers reported that upon seeing the problem statement they already had access to all or some of the information needed to solve the problem. Overall, 27.5% of winning solvers reported doing completely de-novo solution search, relying neither on previous solutions developed by themselves or others (through a literature search or knowledge of the work of others). The remaining 72.5% of winning solvers stated that their submissions were partially or fully based on solutions previously developed by themselves or others. A similar pattern of using previously generated solutions to submissions was reported by non-winning solvers. We tested the response patterns between winners and non-winners using a hierarchical log linear model. The results revealed no significant difference in response patterns (Likelihood ratio chi square = 20.678, df = 15, p =0.147; Pearson chi square = 15.105, df = 15, p = 0.444).

Finally, 10.62% of respondents reported working in teams to solve the problem (8.8% of winners (n=3) and 11.3% of non-winners (n=31) indicated that they had engaged in a team effort). Average team size was 2.91 members (s.d.: 1.65), with no significant difference in team size for winning versus non-winning solvers. Most solvers (79.6%) also reported that they did not consult with others (excluding team members, if any) during the development of their solution (reported by 83.3% of winners and 73.8% of non-winners).

Overall our survey sample is representative of the submitter population for key variables in the analysis. However the respondents are more skewed towards problems that had lower award values, more likely to be Paper/Theory, and have more participants competing to solve them. Our study should also be robust to common methods bias (Podsakoff et al. 2003) as we utilize two independent sources of data and the key independent variables derived from the questionnaire rely on a minimal amount of subjective judgment on behalf of the respondents.

Descriptive statistics of the variables under consideration in the regression analysis for each stage are presented in Table 2(A&B).

<Insert table 2 A & B about here>

Section 7 Findings

The Heckman Probit model estimates of the binary outcome "Did a solver create a winning solution?" are presented in Table 3. We provide probit coefficients and the related robust standard errors.

<Insert table 3 about here>

Model 1 provides a baseline analysis that considers the factors implicated in submitting a solution (stage 1) and the relevant control variables in predicting whether a submission was chosen to be a winner (stage 2). Analysis of the first stage shows that, consistent with the findings in the economics literature, out of the population of solvers that open a problem statement, women are less likely to self-select and enter into competition and submit a solution. We also find that a match between the problem discipline and a solver's own scientific interests profile is significantly related to submitting a solution for evaluation. We note that increasing size of the award discourages entry as does the requirement for an RTP solution. These two variables could be considered proxies for problem difficulty and thus the results appear to be intuitive. The more problems a solver has opened in the past, the more likely they are to submit a solution to the current problem. The ethnic background of the solver has no bearing on their propensity to submit a solution for evaluation.

Examination of the control variables in the second stage reveals that, as is to be expected, the hours of effort invested by the solver is significant and positively correlated with developing a winning solution. However, the number of scientific interests indicated by the solver, prior

familiarity with the problem, and the match between the problem field and the solver's own scientific interest profile were not statistically significant correlates of developing a winning solution. The Wald Chi Square test of independent equations is statistically significant, indicating that the two-stage selection model is better suited for the analysis under consideration than a one-stage model.

Model 2 introduces the first independent variable in the second stage, Expertise Distance, which is the self-assessed distance between the problem and the solvers' field of expertise. The coefficient for this variable is positive and significant at the 10% level, indicating that increasing distance between the problem and the solvers' field of expertise leads to a higher probability of developing of a winning solution. The significance of the control variables in the second stage remains as per the baseline model. In addition, the first stage variables do not have any material change in their sign and significance and the Wald Chi Square test of independent equations continues to indicate the suitability of a two-stage selection model.

Model 3 removes the Expertise Distance variable and introduces our second independent variable, Gender. The coefficient on Gender is positive and significant at the 1 percent level, indicating that those who reported their gender to be female were more likely to have created a winning solution. Once again, there is no change in the significance of the second stage control variables; nor do the first stage variables change materially. The Wald Chi Square test statistic indicates that two-stage selection model remains an appropriate estimation strategy.

Model 4 is the preferred model as it contains both of the independent variables of interest, Expertise Distance and Gender, in the regression analysis. The coefficient for Expertise Distance is found to be positive and significant at the 5% level, indicating a positive relationship between the self-assessed distance between the problem and the solvers' field of expertise and the creation of a successful solution. Thus, winning solvers are, on the margin, solving problems that are

further away from their field of expertise than non-winning solvers. This result supports Hypothesis 1 by demonstrating that successful solutions in a broadcast search setting will be positively associated with increasing distance between the solvers' field of expertise and the focal field of the problem. The magnitude of the effect is such that for every increment increase in the self-assessed "Problem-Expertise Distance" scale, the odds of creating a winning solution increase by 3.3% (significant at the 10% level with a standard error of 0.017).

We also find support for Hypothesis 2, which states that successful solutions in a broadcast search setting will be positively associated with being a woman. Model 4 shows that those who reported their gender to be female are significantly more likely (at the 1% level) to have created a winning solution. In this case, the magnitude of the effect is such that the probability of winning increases by 23.4% if the individual submitting a solution is female (significant at the 1% level with the standard error being 0.073). We also examined quadratic and interaction terms for our two independent variables and found them to be non-significant (not reported here).

It is also interesting to note that the simultaneous inclusion of both independent variables in the regression analysis enabled the scientific interest count variable in the controls to achieve significance at the 10% level. The negative coefficient on the scientific interest count implies that in a fully specified model, solvers who indicate fewer scientific interests, i.e. specialists, are more likely to develop winning solutions. Finally, the first stage variables remain unchanged and the Wald Chi Square test of independent equations is statistically significant, indicating that the two-stage selection model is preferred over a simpler one-stage model.

Robustness Indications

We conducted several additional analyses to test for robustness of our findings. First, we also reran our two-stage regression (Model 4) with bootstrap sampling and estimation of the standard errors (not reported in the paper). Bootstrap is used if there is concern about the

sampling distribution in analysis. The method works by randomly selecting observations from the sample with replacement and estimating standard errors based on this random sampling. Our bootstrap model with 100 replications revealed no material changes to our findings.

Second, since our survey sample consisted of respondents from 93 of the 166 broadcast problems, we reran our regression and limited the first-stage observations to only those that had downloaded those particular problems. This limited the pool of observations to 9074 (from 12786) in our analysis. There was no material change in the sign, magnitude or significance of the main results with the limited sample.

Third, approximately 10% of our sample reported creating a solution as a team and we did not request problem expertise distance assessments or ask about the gender make-up of the team in our survey. To test for the potential bias of these omissions, we first included in our regression a binary variable for using team in the second stage model. The inclusion of the team variable did not impact our results and was in itself not significant. As an additional step we removed from our analysis all observations that indicated the usage of a team. This reduced our second stage sample by 36 observations (from 320 to 284) and resulted in the Expertise Distance variable having a slightly reduced coefficient (from 0.87 to 0.80) and significance (from $p = 0.05$ to $p=0.11$) attributable to the smaller sample.

Finally, in our survey we gathered data on respondents' education level – which we did not consider in our main analysis for parsimony reasons. Including a binary variable for doctorate achievement in the analysis did not materially change our findings.

Limitations

We acknowledge a few important limitations of our empirical analysis. We derived a technical marginality score by having survey respondents self-assess the distance between the problems they were attempting to solve and their respective fields of expertise. There may be

concerns that both the ability of solvers to accurately gauge this distance and status differences amongst fields, in that solvers in lower status fields may perceive a smaller distance whereas those in higher status fields may perceive a larger distance, may create errors in this measurement. Some of these concerns may be allayed by recalling that most solvers had doctorates in scientific disciplines and spent, on average, more than a week (42.7 hours) creating solutions to their problems. Given their specialized background and training and the considerable effort they expended on formulating solutions, their self-assessment of the distance between their expertise and the problem field can probably be assumed to be accurate.

We also need to consider the process by which problem holder firms select winning submissions. Given that in most cases, firms had expended considerable prior internal effort unsuccessfully trying to solve these problems, the winner selection process might be biased towards "out-of-field" solutions, that is, solutions that appear to be quite different from internal attempts. We do not know what internal dynamics drove the seeker firms' selection of problems for broadcast in the first place. Perhaps firms were selecting problems they considered non-strategic or externally solvable. Therefore, we need to be cautious about our ability to extrapolate our findings to all type of problems that a seeker firm may face. However, the challenges broadcast were not "fun" or toy problems; the firms that posted them were seeking to resolve real scientific issues that had proved intractable to their own laboratories, and were willing to pay substantial sums for viable solutions. Utterly "outlandish" solutions that could not be absorbed within the capabilities of the problem holder firms would thus probably not be selected.

Section 8 Discussion and Conclusion

Broadcast search involves a problem solving process that is unconventional from traditional search methods employed inside of organizations. Here instead of problem holders searching for a solution, external solvers, not affiliated with the initial problem, self-select

themselves to create a solution. Problem holders transform from being solvers to solution seekers and their objective becomes to attract and evaluate solutions from other solvers. Overall, our results indicate that technical and social marginality are statistically related to problem solving success in a broadcast search setting.

The positive and significant relationship between marginality in terms of being distant from the field of the problem and problem solving success suggests that successful solvers were able to bring relevant novel perspectives and heuristics to the problem in question that bridged knowledge fields. Two examples of InnoCentive.com challenges illustrate the importance of marginality in broadcast search. The first concerns the submission of different winning solutions to the same scientific challenge of identifying a food-grade polymer delivery system by an aerospace physicist, a small agribusiness owner, a trans-dermal drug delivery specialist, and an industrial scientist. In this case, all four submissions approached the problem at hand with very different solution approaches that were "native" to the respective backgrounds of the problem solvers but very novel to the seeker. All four submissions successfully achieved the required challenge objectives with differing scientific mechanisms indicating the presence of different perspectives and heuristics on the same problem.

The second involves an R&D lab that, even after consulting with internal and external specialists, did not understand the toxicological significance of a particular pathology that had been observed in an ongoing research program, leading the problem holder firm to broadcast the problem via IC. It was eventually solved, using methods common in her field, by scientist with a Ph.D. in protein crystallography who would not normally be exposed to toxicology problems or solve such problems on a routine basis. The original problem holders had not anticipated a crystallography-based solution to their problem. In both of these cases, the successful solvers used "local" knowledge to formulate a solution to a problem in a relatively distant field.

An interpretation of technical marginality finding would be that the best way to solve problems is to have experts from vastly different fields attempt solutions, however, we urge caution in extrapolating the technical marginality finding to the extreme. Indeed one might anticipate an "inverse-U" relationship between problem solving effectiveness and technical marginality and that our analysis – based on the self-selection of individuals to problems – has focused on the increasing slope side of the inverted-U. . Thus the technical marginality finding is conditional on self-selection by solvers into solving the problem, i.e. solvers themselves have made an assessment about the relevance of their knowledge field to the problem at hand prior to submitting a solution and those that assessed themselves to be very "far" may never have participated.

Being female was positively and significantly related with being a winning solver. Because women have been documented in the literature to have lower participation rates in high status science careers, we found them to be a good proxy for social marginality. The strong effects showing women to be more successful solvers stand in contrast to what studies that have given rise to the "productivity puzzle" have found, namely, that women are generally less productive than men in science (Cole and Zuckerman 1984). This suggests the existence of a pool of "outsiders" who would evidence higher variance in their problem solving approaches and greater likelihood of seeing problems in fresh, unconventional ways. Due to their marginal position, women might be able to devise novel perspectives and search algorithms to the problem at hand that may not be available to men. This, combined with a gender-blind review process, ensures that winners are selected on the merit of their submissions and judges are not biased by pre-conceived gender roles and abilities (Goldin and Rouse 2000).

Alternatively, perhaps broadcast search taps the potential of what might otherwise be lost talent located in marginal structural positions. Thus the gender effect might be driven by self-

selection. It might simply be that the women who participate in broadcast search and solution attraction are of a higher caliber than most of the men who participate. In line with previous studies (Croson and Gneezy 2009; Niederle and Vesterlund 2007), our results suggest that women are more reluctant to enter into competitions (as shown by the negative and significant coefficient on Female in first stage of our regression). It may be that women enter the competition only if they are very confident that they have a winning solution and therefore we find high quality contribution from this group. The preponderance of similarly talented men might be toiling inside organizations and unable to participate in such problem solving challenges. Their marginal career positions in the various fields of science might afford highly talented women more freedom and latitude to develop successful solutions. As the majority of participants in our setting are male, the presence of a self-selection effect among female solvers might usefully inform the broader question of the status of women in science. Yet another explanation of the relationship between being a women and being a winning solver is the possibility that talented women scientists are actively using the broadcast search setting as a venue for signaling their ability in problem solving and as a place to obtain recognition of their work that may not be possible elsewhere.

There is an inherent tension between the importance of social marginality for broadcast search and the literature on women in science, which hints at the negative consequences for women of being marginalized. Broadcast search leverages the high variance of problem solving approaches from the distribution of marginal individuals. Obviously, broadcast search merely takes the optimal matching solution from this distribution, and thus the likelihood of being picked as a winner from a pool of marginal individuals is still extremely low. Therefore, the vast majority of the population will not obtain any positive effect from the fact that broadcast search seems to reward individuals in marginal positions.

Thus, McLaughlin's (2001) concept of "optimal marginality" applies to the broadcast search setting. Optimal marginality implies having access to and knowledge of the problem field as well as access to resources without being tied to the intellectual traditions of that field. Our results seem to point to a variation of the notion of optimal marginality. The open broadcast of problem information in our setting probably enables optimally marginal individuals to self-select to problems to which they can apply solutions they have already developed in different contexts and settings. Here optimal marginality denotes the position in which individual solvers are sufficiently distant from conventional approaches to generate a novel solution that would not be if the solver had been part of the core of the established field of the problem. On the other hand, the solver is at the same time not too distant from the problem, because they now have access to interesting problem information, to apply relevant perspectives and heuristics.

Our research adds to the literature on open innovation processes (Chesbrough 2002; von Hippel 1988, 2005). So far studies have mainly investigated instances in which the focal "problem holding" organization is the central and proactive search agent in the solution seeking process (Laursen and Salter 2006). We draw attention to the context in which the problem holding organization avoids being in the "driver's seat" of search by using broadcast search. Our results speak to the potential of openness by highlighting the importance of including hitherto excluded marginal participants in the solving problems process via the removal of barriers to entry for participation for non-obvious individuals and facilitating self-selection of solvers to problems. In this way organizations gain access to solutions that they, despite being open, would not have found through their own searches. Since broadcast search yields solutions from individuals that are typically "under the radar," who possess alternative knowledge and approaches to the problems that are not within the normal purview of the problem domain, broadcast search can be considered a complement to the existing portfolio of search strategies used by organizations.

Finally our analysis of broadcast search also has implications for the knowledge-based theory of the firm and the potential for a problem-solving perspective to guide the choice between internal and external activities (Nickerson and Zenger 2004). The fact that only a third of the problems that were broadcast were deemed solved by the seeker firms through a market mechanism, like a research contest, indicates that not all decomposable problems are solvable. However, the large proportion of failures may provide a valuable signal to the firm that either the problems have not been properly decomposed, i.e. there are too many latent complex interactions in the problem itself, or that the way the problem has been conceived is not amenable to a solution.

More generally the act of problem decomposition by firm managers and employees raises questions about problem design and definition. The ability of marginal individuals, with different perspectives and heuristics, to come up with novel solutions to broadcast problems, indicates that they may be conceiving of a given problem in a different way than the seeker. Thus problems should not be considered as fixed and given but open to redefinition by the solvers themselves. Therefore while managers may play a central role in choosing problems and the institutional mechanism for having them solved, the inclusion of broad external and marginal perspectives on the problem design and definition phase may also be valuable and perhaps make problems more "solvable." Hence broadcast search may be applicable to both finding the answer but also perhaps defining the problem.

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Figures and Tables

Figure 1 – Broadcast Search Process

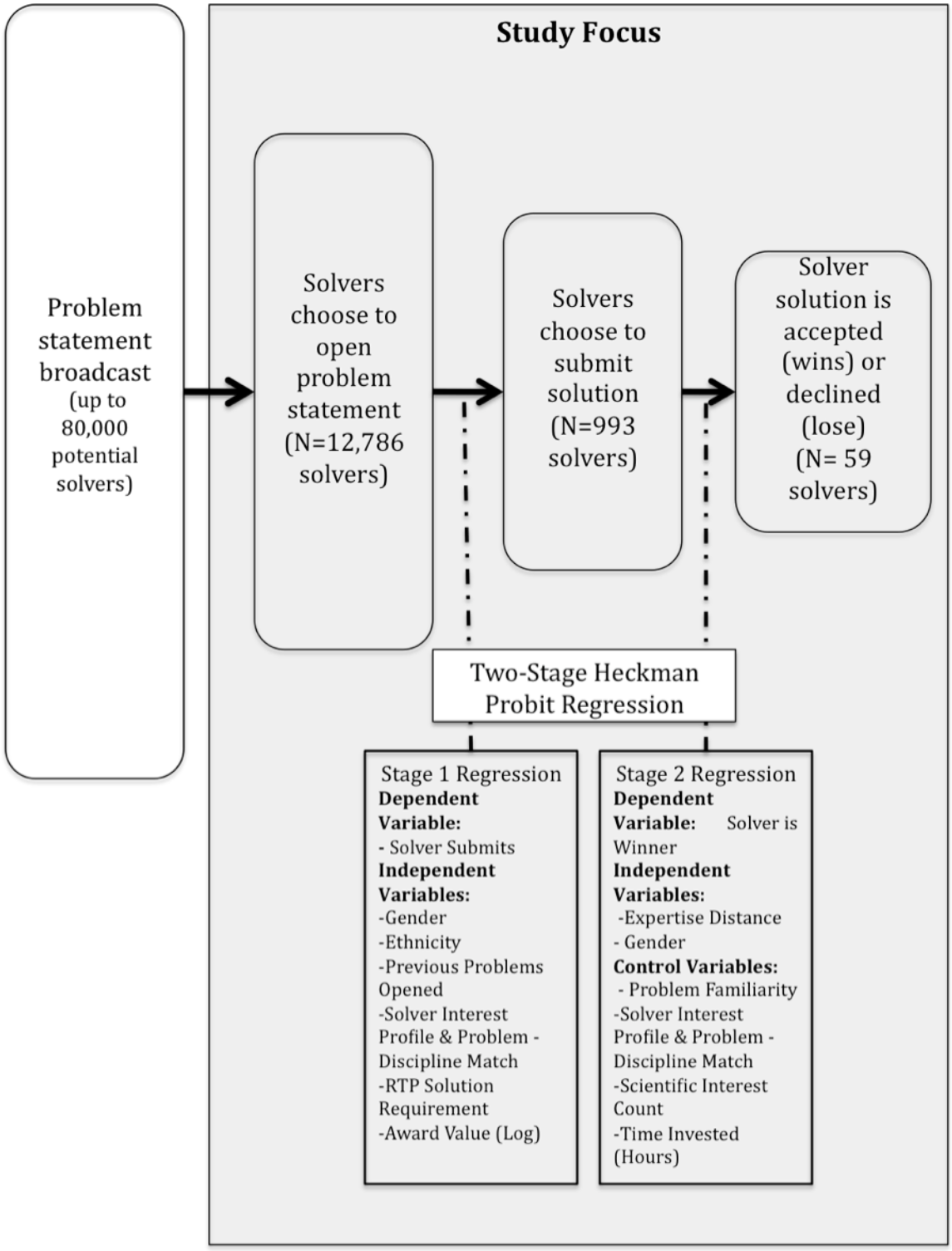


Table 1A and 1B - Contrasts (mean-based) Between Survey Respondents and Non-respondents in Submitter Population

Table 1-A - Problem Contrasts

	Survey Respondents	Survey Non-Respondents	p-value
Problem Characteristics	N = 93 Problems	N=73 Problems	
Problem award value	$24.918	$35.767	0.001
Percentage of problems that were RTP	44%	75%	0.000
Number of individuals opening problem	307	157	0.000
Number of submissions	14.8	3.6	0.000
Percentage of problems deemed solved	39.70%	16.40%	0.001

Table 1-B - Individual Contrasts

	Survey Respondents	Survey Non-Respondents	p-value
Solver Characteristics	N =320 Individuals	N=673 individuals	
Gender (Female =1)	10%	11%	0.765
Ethnicity (Anglo = 1)	24%	23%	0.918
Interest Count	10.04	9.53	0.539
Solver Interest Profile and Problem Discipline Match	47%	42%	0.176
Previous Problems Opened	9.90	6.00	0.000
Problem Award Value	$18.429	$23.526	0.000
Percentage of problems that were RTP	30%	46%	0.000

Table 2-A Descriptive Statistics for Variables in First Stage of Heckman Regression (N=12,786)

	Mean	S.D.	Min	Max	Submit Solution	Gender (Female=1)	Ethnicity (Anglo Saxon=1)	Solver Interest & Problem Discipline Match	Previous Problems Opened	RTP solution requirement	Award Value (Log)
Submit a Solution (First Stage Dependent Variable)	0.025	0.156	0	1	1						
Gender (Female=1)	0.156	0.363	0	1	-0.025	1					
Ethnicity (Anglo Saxon=1)	0.28	0.449	0	1	-0.014	-0.041 **	1				
Solver Interest & Problem Discipline Match	0.371	0.483	0	1	0.031 **	0.002	-0.033 **	1			
Previous Problems Opened	2.694	3.864	1	110	0.303 **	-0.037 **	-0.015	0.004	1		
RTP Solution Requirement	0.588	0.492	0	1	-0.094 **	-0.002	0.000	-0.037 **	-0.059 **	1	
Award Value (Log)	9.987	0.94	7.60	11.56	-0.083 **	-0.006	-0.017	-0.042 **	-0.015	0.684 **	1

** p <5%,

Table 2-B Descriptive Statistics for Variables in Second Stage of Heckman Regression (N=320)

	Mean	S.D.	Min	Max	win	Problem familiarity	Solver Interest & Problem Discipline Match	Scientific interest count	Time Invested (Hours)	Expertise Distance	Gender (Female=1)
Solver Winner (Second Stage Dependent Variable)	0.119	0.324	0	1	1						
Problem familiarity	4.009	1.612	1	7	-0.05	1					
Solver Interest & Problem Discipline Match	0.466	0.5	0	1	0.006	0.08	1				
Scientific interest count	10.047	11.306	0	56	0.014	0.036	0.324 **	1			
Time Invested (Hours)	42.789	117.572	0.1	1440	0.216 **	-0.075	-0.004	0.067	1		
Expertise Distance	2.884	1.794	1	7	0.088	-0.406 **	-0.097	0.156 **	0.024	1	
Gender (Female=1)	0.1	0.3	0	1	0.103	-0.021	0.002	0.062	-0.065	0.045	1

** p <5%,

Table 3 Heckman Probit Model for Predicting Which Solver Submits a Winning Solution

	Model 1		Model 2		Model 3		Model 4	
Variables	Probit Coefficient	Robust Standard Errors	Probit Coefficient	Robust Standard Errors	Probit Coefficient	Robust Standard Errors	Probit Coefficient	Robust Standard Errors
Second stage: Solver winner								
Control Variables								
Problem Familiarity	0.029	0.052	0.075	0.057	0.038	0.051	0.086	0.055
Solver Interest & Problem Discipline Match	-0.069	0.174	-0.030	0.177	-0.067	0.172	-0.033	0.175
Scientific Interest Count	-0.009	0.008	-0.012	0.008	-0.011	0.007	-0.015	0.007*
Time Invested (Hours)	0.002	0.001***	0.002	0.001***	0.002	0.001***	0.002	0.001***
Constant	0.061	0.305	-0.339	0.371	0.031	0.316	-0.376	0.376
Independent Variables								
Expertise Distance			0.085	0.044*			0.087	0.045**
Gender (Female =1)					0.669	0.228***	0.671	0.231***
First stage: Submit a solution								
Gender (Female = 1)	-0.158	0.087*	-0.156	0.087*	-0.195	0.088**	-0.195	0.088**
Ethnicity (Anglo Saxon = 1)	-0.054	0.060	-0.051	0.060	-0.058	0.060	-0.055	0.060
Previous Problems Opened	0.078	0.008****	0.078	0.008****	0.078	0.008****	0.078	0.008****
Solver Interest & Problem Discipline Match	0.171	0.052***	0.171	0.052***	0.171	0.052***	0.171	0.052***
RTP Solution Requirement	-0.265	0.069***	-0.264	0.069***	-0.264	0.069***	-0.264	0.069****
Award Value (Log)	-0.158	0.032****	-0.158	0.032****	-0.158	0.032****	-0.158	0.032****
Constant	-0.653	0.294**	-0.658	0.294**	-0.648	0.294**	-0.656	0.293**
Selection Correction Term	-0.749	0.143****	-0.767	0.149****	-0.800	0.147****	-0.825	0.156****
Wald Chi Square for independent equations:	27.54****		26.41****		32.20****		28.17****	
Number of observations (Stage 1): 12786								
Number of censored observations: 12466								
Number of uncensored observations (Stage 2): 320								
*p at 10%, **p at 5%, ***p at 1%, ****p at 0.1% significance level. Standard errors are clustered by broadcast problems.								