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PROCURING INNOVATION ON INTERNET-BASED MARKETS

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Abstract

The Internet-based market is rising as a viable venue for the procurement of innovation solutions. There are two major procurement mechanisms existing in the market practices: contest and RFP. We investigate the factors that affect a firm's preference of one mechanism over the other. We divide innovation problems into two categories: exploitive innovation problem and exploratory innovation problem. For an exploitive innovation problem, technologies used in solutions already exist, and the outcome of the solution is determined by the type and the effort of a solver. For an exploratory problem, technologies are not available; solvers need to go through an exploratory process but the result of his effort is uncertain. We establish the boundary condition for solution seeker's decision on procurement mechanism. For an exploitive innovation problem, RFP is preferred in an open-participation market unless the distribution of the solvers' type has a big variance; for an explorative innovation problem, contest will be preferred in most cases except that the solver pool of the market is small. Moreover, the amount of a cash award, the effort coefficient, and the degree of the randomness endowed in a technology exploratory process all have effect on seekers' decision.

Keywords: Internet-based innovation markets, contest, RFP, open innovation

Introduction

In a world of the distributed knowledge, firms and institutions need to leverage outsiders' wisdom to solve their own innovation problems. Instead of solving the problem completely in-house, they have begun to either work with outside partners or procure solutions from market. This movement is termed as open innovation by Chesbrough (2002). With the involvement of the Internet, the open innovation has grown more open to participants and to various scopes, because the Internet not only creates a viable environment for innovators to communicate and collaborate with each other but also incubates a variety of markets to embrace all sorts of innovation problems.

Some procurement markets for innovation have emerged in recent years. InnoCentive, as one of the best-known online innovation markets, takes up innovation problems in a broad range of domain such as computer science, chemistry, physical sciences, life sciences, etc. The problems that come from the "seekers" who are either companies, or non-profit organizations or public sectors are opened up to the "solvers" who are scientists, researchers or innovators. As of 2008 InnoCentive had 64 of these seekers posting more than 800 problems in 40 disciplines. More than 300 of them have already been solved by over 165,000 solvers.1 Contest is the main transaction mechanism used in InnoCentive, in which the solver with the best solution wins cash award. Another transaction mechanism is RFP (known as eRFP in InnoCentive) which allows a seeker to submit a Request for Proposal to the solver's community. After a number of solvers turn in RFP responses, the seeker will select the best RFP response by his evaluation and contact its submitter for further development.

Contest and RFP are the most common mechanisms for innovation procurement. Some markets apply both of them (e.g. InnoCentive), while others adopt only one (e.g. Innovation Exchange uses Contest and NineSigma uses eRFP). Specifically, contests used in these markets are tournaments that reward the provider of the best solution on a specific date. In the tournament, a solution is pre-prepared by a solver. If it does not rise as the best solution, all the costs spent on the solution will be sunk. In contrast, RFP eliminates the sunk costs by choosing proposals rather than fully completed solutions. The provider of the best proposals will be rewarded with a contract to develop his proposal into a solution. Although to prepare proposals generates cost, it is much less costing than the full development of a solution.

Economists have long believed that innovation is uncontractable because its inputs are unobservable and its outcomes can hardly be verified by a court. Though, the adoption of RFP by real innovation markets reveals that at least some of the innovations can be contracted, and under certain circumstances, RFP works better than contest as an innovation procurement mechanism. However, it is unclear in which types of innovations and under what circumstances RFP

1 en.wikipedia.org/wiki/InnoCentive

outperforms contest or vice versa. Our paper aims to address those questions.

In our paper, we view innovation as a process of searching over some poorly understood knowledge landscape (Simon and Newell 1962; Levinthal 1997). We divide the unknown landscape into two areas. One is associated with not knowing who the best solver of a problem is; the other is associated with missing technologies to solve problems. We define the problems in the former area as exploitive innovation problems and in the latter as exploratory innovation problems. For an exploitive innovation problem, technologies are ready. The objective of seekers is to find the right solver who makes the best use of the technologies. For an exploratory innovation, in contrast, technologies do not exist yet and the seekers must drive solvers to invent them. The quality of the final solutions for both problems is characterized with uncertainty. The uncertainty in exploitive problems is related to the endowed characteristics of solvers; while the uncertainty in exploratory problems mainly lies in the random results of inventions.

Let us take a real case as an example. The Oil Recovery Institute needed to find a new and novel way to get oil of the bottom of the ocean near Alaska. They could get the oil off the bottom and onto the barges, but the surface temperature drops so dramatically that the oil solidifies and cannot be pumped through the barge system. The solver ended up being an engineer who solved that problem using a common technology in the construction industry. He recognized that problem was very similar to the problem of keeping cement liquid while people pouring a foundation. Thus, he suggested the Institute to use vibrating equipment on the barges to keep the oil fluid enough. In this case, the technology is already available, and the winner is who recognized it. Therefore, we categorize this problem as an exploitive innovation problem. For another instance, the Prize4Life foundation featured a $1 million award for finding a biomarker that measures ALS disease progression, in which case the technology was not unavailable and solvers needed to invent it. Therefore, from our perspective, it is an exploratory innovation problem.

In our paper, we model two types of innovation problems and study each problem of under which conditions a seeker will prefer to RFP or vice versa. We find that in an exploitive innovation problem, a seeker's decision is affected by both the size and the diversity of the solver pool in the market, and also that the value of the problem which is presented by the amount of cash awards influences seekers' preference to a mechanism. In an exploratory innovation problem, the main influential factor is the number of solvers and the randomness of the exploratory process. The trade-off behind the choice between contest and RFP is related to the advantage and the side-effect a contest has in a given setting. When the advantages overwhelm the side-effects, contest is preferred, otherwise, RFP wins out.

The remainder of this paper is organized as follows. We first review the relevant literature, then develop the models and establish our main results. Finally, we conclude the paper.

Literature Review

There is a set of papers focusing on the optimal tournament design in R&D settings (e.g., [2] [4] [5] [8] [11]). All of these papers find that allowing open participation in tournaments mitigate sponsors' profits, because the fierce competition between solvers causes their underinvestment in effort. To reduce this inefficiency, Taylor (1995) suggests sponsors restricting participation by taxing contestants through an entry fee [11]; Fullerton and McAfee (1999) demonstrate that an all-pay auction for the entry fee is efficient to select the most qualified contestants for competition [4]; Fullerton et al. (2002) shows that conducting auctions at the end of research tournaments will generally reduce the sponsor's prize expenditure relative to fixed-prize tournaments [5]. However, Terwiesch and Xu (2008) have an arguing result. They analyze three types of innovation project: a) expertise-based project, b) ideation project and c) trial-and-error project, and demonstrate that for all the types of innovation, the seeker can benefit from open-participation contest "because he can obtain a more diverse set of solutions, which mitigates and sometimes outweighs the effect of the solvers' underinvestment in effort" [12]. Unlike this stream of literature, our paper not only discusses the effect of the number of participants on seekers' profit but also provides a new insight into the effect of the distribution characteristics of participants.

Moreover, Terwiesch and Xu (2008) compared the quality of the solutions and the seekers' profits in a contest and in an internal innovation. They suggested that the benefit of contest is enabling seekers to find solvers with low effort cost, while the ineffiency of contest is causing the underinvestment in the solvers' effort. They further demonstrated if the external solver's effort cost is lower than certain level, open contest is a better choice than internal innovation. On and beyond Terwiesch and Xu (2008), our paper concerns seekers' choice between two procurement mechanisms: contest and RFP. Assuming that seekers are able to find solvers at the same effort cost in these two mechanisms, to reach the low cost solver is no longer the only benefit out of contest.

Thus, the reason behind a choice decision on contest or RFP is different from that on contest and internal innovation.

Another relevant literature stream is related to the research on RFP. In the real world, RFP is widely used in product procurement. The process is usually regarded as a multi-attribute auction in academy (e.g. [1] [10]). However, in our paper, we abstract the process into a model of price-only auction in which seekers set compulsory quality requirements for all the bidding solvers to accept. Based on our observation, the problems posted in real innovation markets are describable with the explicit quality requirements on solutions. Therefore, we believe that our price-only model does not reduce the explanation power of our results. More specifically, we assume that solvers compete for contract via the Vickrey second-bid auction in RFPs. This assumption is based on two facts. First, we have observed many English auctions in real innovation markets. Second, the outcome of the English auctions can be achieved by Vickrey auction, and it is customary to model an English auction as a Vickery auction [7].

Model Development

A seeker procures a problem solution from n solvers. All parties are risk-neutral. The value of a solution is determined by three variables, solvers' type, solvers' effort and a random noise. A solver's type is a combination of all his/her endowed characteristics related to solving the problem, such as experience, education, intelligence, etc. A solver's effort is the investment s/he puts into the problem, which usually refers to time and research resources. Besides the type and effort of solvers, all the other factors that influence the value of a solution are regarded as the random noise. Formally, the value of a solution V_i can be written as a linear function of solvers' type β_i, solvers' effort return r(ei) and a random variable ξ_i:

$$V_i = \beta_i + r(e_i) + \xi_i,\ \ i = 1, 2, ..., n \qquad (1)$$

β_i is independently distributed across solvers with a commonly known, continuous and increasing cumulative density function $F(\beta_i)$. $r(e_i)$ is either linear or concave in e_i. The cost of the solution is linear in effort with a constant unit cost c. ξ_i is an IID Gumbel random variable with mean zero and scale parameter μ. A higher μ means a higher degree of randomness. β_i is private information of solver i; c and μ are commonly-known information.

A contest has three stages. Firstly, a seeker posts a problem and announces a cash award, A, for the best solution. Secondly, solvers first decide how much effort to exert on the problem and then work out the solution. Finally, after all the solvers submitted their solutions, the seeker selects the best solution and pays the prize to its solver. Let V_1, V_2, …, V_n, denote the rank-ordered values of solutions, where $V_1 \geq V_2 \geq \ldots \geq V_n$. The profit of the seeker (the subscript c stands for contest) is

$$\Pi_c = V_1 - A \qquad (2)$$

In a RFP, which is assumed as a Vickrey auction in our paper, a seeker firstly posts a problem and specifies the standard value, V, of the solution. Then, according to the value requirement, solvers decide how much to bid for the problem. The seeker will choose the lowest bidder as the winner and pay him the second lowest bid. A solver's optimal bidding truly reveals its cost. Let C_1, C_2, …, C_n , denote the rank-ordered costs of the solvers, where $C_1 \leq C_2 \leq \ldots \leq C_n$. The profit of the seeker using a Vickrey auction (the subscript r stands for RFP) is

$$\Pi_r = V - C_2 \qquad (3)$$

As we can see, a seeker's profit function is the value of the winning solution minus the reward paid to the winner. Assuming the seeker pays the same rewards to the winners in contest and RFP ($A=C_2$), we can compare the performance of the two mechanisms by examining the expected values of their winning solutions (V_1 and V). For consistency, we denote V_c as the value of winning solution in contests and V_r as the value in RFP.

Mechanism Comparison in Exploitive Innovation

As we defined, an exploitive innovation problem has available technologies and the uncertainty of the quality of its solution lies on the characteristic of its solver. Assuming the value of a solution equals to its quality, we believe that the solution value in an exploitive innovation problem is only driven by the type and effort of solvers. Terwiesch and Xu (2008) define this kind of innovation as expertise-based projects.

$$V_i = \beta_i + r(e_i) \qquad (4)$$

In a contest, for a given solver i, the probability for him to win the contest equals to the probability that the solver offers the solution with highest value. Let P_i (β_i, $F(\beta_i)$, n) denotes the probability of the solver i offering the best solution. Thus, each solver solves:

$$\underset{e_i}{Max} \quad E[\pi_i(\beta_i)] \equiv \pi_i = AP_i(\beta_i, F(\beta_i), n) - ce_i, \qquad (5)$$

$$\text{s.t. } \pi_i \geq 0$$

We assume e_i is increasing with β_i and $r(e_i)=\theta e_i$, in which θ is defined as effort coefficient. V_i increases with, therefore,

$$P_i(\beta_i, F(\beta), n) = F^{n-1}(\beta_i) \qquad (6)$$

The problem of solver i can be written as

$$\underset{e_i(\beta_i)}{Max} \quad \pi_i = AF^{n-1}(\beta_i) - ce_i(\beta_i), \text{ s.t. } \pi_i \geq 0 \quad (7)$$

The first order condition of solver i's problem is

$$A(n-1)F^{n-2}(\beta_i)f(\beta_i)\frac{\partial \beta_i}{\partial(e_i^*(\beta_i))} - c = 0$$

which can be rearranged as

$$\frac{\partial(e_i^*(\beta_i))}{\partial \beta_i} = \frac{A(n-1)F^{n-2}(\beta_i)f(\beta_i)}{c}$$

We assume $\beta_i \in [\beta_0, \beta_1]$. Since V_i increases with β_i, the solver with the lowest type has no probability to win and will not exert any effort in equilibrium, i.e., $e(\beta_0) = 0$. Solving the differential equation with this boundary condition, we have the symmetric Bayesian equilibrium strategy for a solver as

$$e_i^*(\beta_i) = \frac{A(n-1)}{c}\int_{\beta_0}^{\beta_i} F(x)^{n-2} f(x)dx = \frac{A}{c}F^{n-1}(\beta_i) \quad (8)$$

Since $F(\beta)$ is continuous and increasing in β_i , we can verify that $e(\beta_i)$ is increasing in β_i, which is consistent with our assumption. Substituting (8) into (7) yields

$$\pi_i^* = AF^{n-1}(\beta_i) - c\cdot[\frac{A}{c}F^{n-1}(\beta_i)] = 0 \quad (9)$$

Let β_1, β_2, …, β_n, denote the rank-ordered types of the solvers, where $\beta_1 \geq \beta_2 \geq \ldots \geq \beta_n$. Since V_i increases with β_i, the solver whose type is β_i creates the solution with the highest value V_1:

$$\begin{aligned} V_c &= V_1 = \beta_1 + e_1(\beta_1) \\ &= \int_{\beta_0}^{\beta_1} [\beta_i + \theta e_i(\beta_i)]nF(\beta_i)^{n-1} f(\beta_i)d\beta_i \quad (10) \end{aligned}$$

In a RFP, the expected value of submitted solutions is equal to the standard quality requested by the seeker. Therefore, the expected effort a solver will exert to solve the problem can be written as

$$e_i(\beta_i) = \frac{V - \beta_i}{\theta} \quad (11)$$

So, the expected cost of solver i is

$$C_i = ce_i(\beta_i) = c\cdot\frac{V - \beta_i}{\theta} \quad (12)$$

Therefore, the payment for the winner in the Vickrey auction, which is equal to C_2 , can be written as

$$C_2 = c\cdot\frac{V - \beta_2}{\theta} \quad (13)$$

As we supposed before, we compare the expected value the seeker obtains when s/he pays the same reward to the winners of the two mechanisms. The condition can be written as

$$A = C_2$$

Substituting (13) into the above equation yields:

$$V_r = V = \beta_2 + \theta\cdot\frac{A}{c} \quad (14)$$

For tractability, we make a specific parametric distributional assumption. In the following text, we assume that the solvers' types are distributed uniformly on $[R\text{-}s, R+s]$, where $R \geq s > 0$. As shown in most statistic texts, the density of the kth order statistic is given by

$$f_{X_{(k)}}(x) = \frac{n!}{(k-1)!(n-k)!}F(x)^{n-k}(1-F(x))^{k-1}f(x)$$

Based on this density, we can derive the expected value of β_i.

$$\beta_i = (R-s) + 2s\cdot\frac{n-i+1}{n+1} \quad (15)$$

Substituting (15) into (10) and (8), we have

$$V_c = \beta_1 + \theta\cdot\frac{A}{c}\cdot\frac{n}{2n-1} = (R-s) + 2s\cdot\frac{n}{n+1} + \theta\cdot\frac{A}{c}\cdot\frac{n}{2n-1}$$

$$V_r = \beta_2 + \theta\cdot\frac{A}{c} = (R-s) + 2s\cdot\frac{n-1}{n+1} + \theta\cdot\frac{A}{c}$$

Proposition 1. For a exploitive innovation problem, let $r(e_i)=\theta e_i$ be the solvers' effort return function and consider a market with n solvers whose types are distributed uniformly on $[R\text{-}s, R+s]$, where $R \geq s > 0$. Given the award to winner is A, and the unit cost of solvers' effort is c, (a) the seeker can get the highest solution value, $R+s+\theta A/c$, by using RFP mechanism in a market with a very large solver pool; (b) the condition for contest outperforms RFP is

$$\frac{1}{n+1}\cdot 2s + \theta\cdot\frac{A}{c}\cdot\frac{1-n}{2n-1} > 0$$

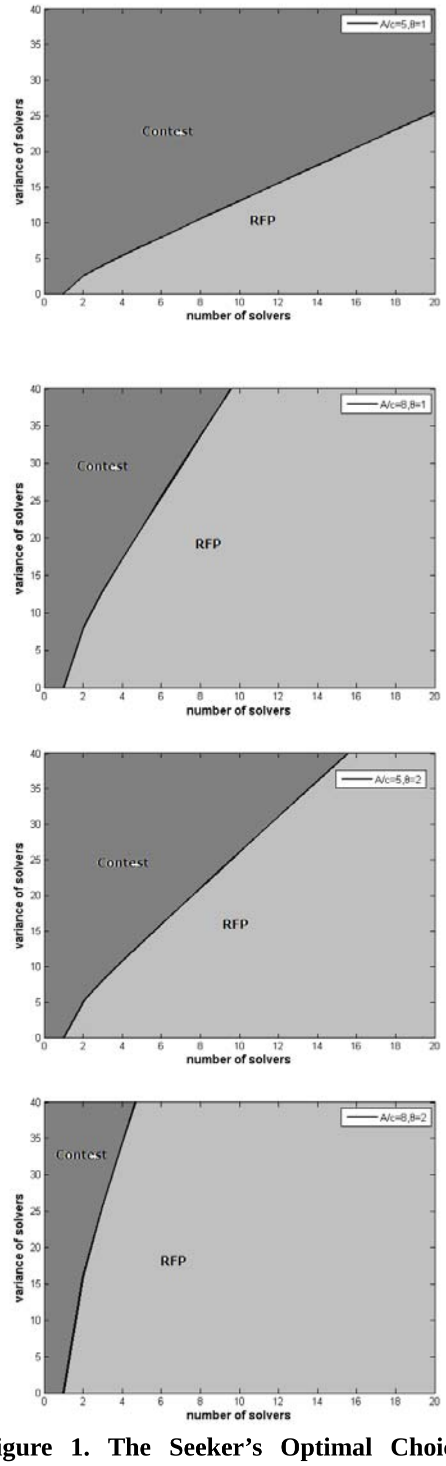


Figure 1. The Seeker's Optimal Choice for Exploitive Innovation Problems

Illustrated in Figure 1 is the seeker's optimal choice of the procurement mechanism for exploitive innovation problems. As demonstrated in Proposition 1 and Figure 1, for certain number of solvers, there is a threshold level of the variance of solver's type. When the variance of solver's type is below the threshold, RFP will help the seeker get a better solution than contest does. The threshold increases in a growing number of the solvers implying that the larger the size of a solver pool, the more likely RFP outperforms contest. In addition, Figure 1 reveals that the ratio of the payment to winner to the unit cost of effort (A/c) has an effect on the seeker's choice. If we normalize the unit cost to 1, the ratio equals to the payment amount. Thus, we may conclude that the more a seeker is willing to pay for a solution, the more likely s/he prefers RFP to contest. In addition, the effort coefficient (θ) has the similar effect, i.e., the bigger the effort coefficient, the more likely the seeker chooses RFP.

Equations (7) and (8) demonstrate the co-existence of the advantage and the side-effect in contest. The advantage is that it can exploit the highest type value of solvers in a pool while RFP only gets the second highest. The side-effect is the underinvestment of effort due to solvers' fear of sunk costs. When the advantage exceeds the side-effect, Contest is preferred; otherwise RFP. In contest, the increase in the number of solvers weakens the chance for a solver to win and causes the solver to be more cautious to invest. Thus, the enlargement of a solver pool will aggravate the side-effect of Contest. On the contrary, the increase of the variance of solvers' type will enhance the advantage of the contest, because with a larger variance, the gap between the highest value and the second highest value is more significant. We conclude that both the size and the diversity of a solver pool will affect the performance of contest and, consequently, seeker's preference to contest or RFP.

As discussed, contest is superior in solver's type while RFP is superior in solver's effort and consequently superior in the return of the effort. Therefore, if the return of the effort accounts for the most value of the solution, RFP will probably outperform contest. The more to be paid for the solution, the larger the solvers' effort is induced. Ceteris paribus, the return of the effort will have a larger proportion in the solution value. Meanwhile, the increase of the effort coefficient will also enlarge the proportion. Therefore, in a setting with large rewards and high effort coefficient, RFP outperforms contest.

Mechanism Comparison in Exploratory Innovation

In an exploratory innovation, there are huge technology uncertainties. To emphasize the technology uncertainty, we assume all the solvers are identical. The difference of the value of solutions mainly depends on the random noise existed in the process of technology exploration.

Terwiesch and Xu (2008) define this kind of innovation as ideation projects.

$$V_i = \beta + r(e_i) + \xi_i$$

In a contest, the winning probability of solver i is

$$\mathrm{Pro}\{\text{i wins the contest}\} = \frac{1}{1+(n-1)\exp\left(\frac{r(e)-r(e_i)}{\mu}\right)} \quad (16)$$

e is the effort exerted by all the other solvers except solver i. We assume they exert the same effort. As for the detailed explanation of Equation (16), we refer interested readers to Terwiesch and Xu (2008). Consequently, the profit of the solver i can be written as

$$\pi_i = A \cdot \frac{1}{1+(n-1)\exp\left(\frac{r(e)-r(e_i)}{\mu}\right)} - ce_i$$

Assuming symmetry $e=e_i$ and $r(e_i)=\theta \ln e_i$, we have the first-order condition

$$e_i = \frac{A\theta(n-1)}{c\mu n^2}$$

The winning solution of the contest has the highest value of random variable, thus

$$V_c = V_1 = \beta + \theta \ln e_i + \max(\xi_i)$$

$$= \beta + \theta \ln \frac{A\theta(n-1)}{c\mu n^2} + \mu \ln n \quad (17)$$

As shown in the above equation, the competition introduced by contest produces two effects. On the one hand, it causes underinvestment of effort, which has been discussed before. On the other hand, it exploits the advantage of multiple solver trials which may produce a random value larger than the zero mean.

With the strategy e_i , the profit of the solver is

$$\pi_i = A \cdot \left(\frac{1}{n} - \frac{\theta}{\mu} \cdot \frac{n-1}{n^2} \right)$$

In order to make sure that the profit of the solver is no less than zero, we obtain solvers' participation constrain

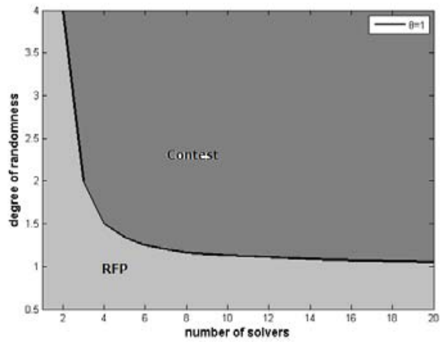
$$\frac{\theta}{\mu} \le \frac{n}{n-1}$$

In a RFP project, since all the solvers are identical, the seeker can choose anyone of them to procure a solution of value V with a payment of $c\exp[(V-\beta)/\theta]$, thus

$$V_R = V = \beta + \theta \ln \frac{A}{c} \quad (18)$$

Proposition 2. For an exploratory innovation problem, let $r(e_i)=\theta \ln e_i$ be the solvers' effort return function and consider a Gumbel random variable with mean zero and scale parameter μ. In a market with n solvers, (a) only when $\theta/\mu \le n(n-1)$, the solvers will consider participating in a contest; (b) the condition for contest outperforms RFP is

$$\frac{\mu}{\theta}\left(\frac{1}{n}\right)^{\frac{\mu}{\theta}} - \frac{n-1}{n^2} > 0$$



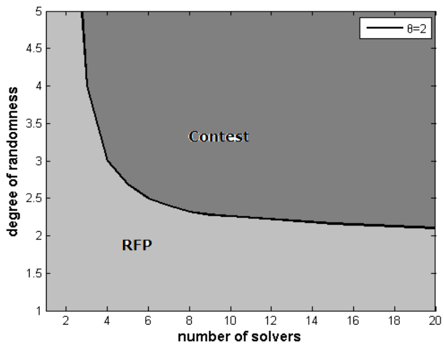


Figure 2. The Seeker's Optimal Choice for Exploratory Innovation Problems

Figure 2 shows that in an exploratory problem, only when the number of solvers is very small, seekers will prefer RFP to contest. Meanwhile, if the random variable has a higher degree of randomness, contest is more likely to outperform RFP. However, with the increase of the effort coefficient, the chance for RFP to win is enhanced.

Comparing Equation (10) and (11), we find the advantage of a contest is that a seeker gets higher value of the random variable because s/he selects the best one from many proposals proposed by a group of contestants, while in a RFP a seeker merely accepts the result produced by one contracted solver. However, in this case, contest has the same side-effect as it has in exploitive problems. The solvers who participate in the Contests may underinvest their efforts because they fear of getting no reward at all. Although the size of solver pool has positive effect on both the advantage and the side-effect, it will induce more advantage than side-effect when it is sized up, thus, the advantage will be dominant. Moreover, when the effort coefficient increases, the effort will account more for the value of the solution and consequently the side-effect of the contest becomes more influential to the solution value. Then, RFP will have more chances to win contest when other factors are fixed.

Discussion and Conclusions

A growing number of firms have embraced the idea of open innovation: looking for ideas and solutions from the outside world. The Internet provides an unparalleled venue for the exchange of virtual knowledge products. E-market has emerged for firms to procure solutions for their innovation problems. However, these markets support different procurement mechanisms and hold solver pools with different quality and quantity characteristics. It is critical for firms to understand which procurement mechanism they should use under certain circumstances.

In an exploitive innovation problem, if a market has a small number of diversified solvers, the seeker (the firm) should use a contest to exploit the full value of the highest solver type. On the contrary, if a market has a large number of similar solvers, the seeker should adopt RFP to obtain solvers' full investment of efforts. Moreover, if the seeker is willing to pay a high reward to the best solution, s/he should choose RFP, since it can induce the best solution of much higher level than contest does. For an exploratory innovation problem, in most cases, a seeker should choose contest unless the size of the solver pool is really small (e.g. $n<5$), or the value of the solution is mainly determined by the effort of solvers rather than the random outcome of the exploratory process.

Although we obtain some explicit results in this paper, there are more questions open to further research. We have observed that solvers' profit varies in different procurement mechanisms. It causes solvers' preference to certain mechanism. It will be interesting to find how this preference influences market structure and seekers' behavior. Moreover, in exploitive innovation problems, seekers' decisions on procurement mechanisms heavily rely on their knowledge of the distribution of solvers' type. An attention is worth in how the information disclosure policy increases seeker's knowledge on the solver's type distribution which in return affects seekers' decisions. Empirical research may be conducted to analyze how seekers choose procurement mechanisms in practice and which factors affect their decisions. We believe that the Internet-based innovation markets will play a significant role in open innovation, but merely a little of these markets has been fully explored. The vast grey portions on the map of the innovation market are left to continuous endeavoring efforts.

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