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Duplicative search ☆

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ABSTRACT

In this paper we examine the dynamic search of two rivals looking for a prize of known value that is hidden in an unknown location, modeled as search for treasure on an island. In every period, the players choose how much to search of the previously unsearched portion of the island in a winner-takes-all contest. If the players cannot coordinate so as to avoid searching the same locations, the unique equilibrium involves complete dissipation of rents. On the other hand, if the players have some (even limited) ability to coordinate so as to avoid duplicative search and the search area is sufficiently small, there is a unique equilibrium in which the full area is searched and each player earns a positive expected return.

1. Introduction

Consider pharmaceutical firms competing in a race to discover a new drug, paparazzi searching luxury hotels for a visiting movie star, bounty hunters pursuing a fugitive, or researchers looking for solutions to the six Millennium Prize Problems in mathematics. All of these scenarios have attributes of a general problem, namely, a treasure hunt for a prize of known value in which there is uncertainty regarding the cost of search. Critically, in each of these cases, a searching party's incentive changes dynamically as search progresses. For instance, a paparazzi's incentive to search depends on the number of remaining unsearched hotels. Similarly, pharmaceutical companies strategically adjust their effort as research into a new medication progresses. The dynamics – and changing nature of search – is critical in each of these problems. In this paper we analyze a dynamic non-stationary search model for a known prize, hidden in an unknown location.

To do this, we develop a model in which two players undertake costly search for a treasure of known value that is hidden somewhere on an island of a given area. We assume that there is an equal probability that the treasure will be located at any given point on the island. In each period, both players make their search decisions simultaneously. Once the treasure is found the game ends. If the treasure is not discovered in any given period, the game continues. In the next period, each player observes the locations that have previously been searched. They then decide how much of the remaining area they wish to investigate. If the treasure is simultaneously discovered – this happens if the two players successfully search the

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same part of the island – both players incur their individual costs but the treasure is destroyed. If a player discovers the treasure on their own, they receive the full value of the treasure, while both players incur their search costs.

First, we consider the case when the duopolists are unable to coordinate to avoid searching the same location. Given its dynamic nature, we analyze a game in which each state is described by the remaining unsearched area. Following Maskin and Tirole (1988), we restrict our attention to symmetric Markov perfect equilibria (SMPE).[1] With uncoordinated search, there is a unique equilibrium in which the potential value of the prize is completely dissipated by excessive search. To provide some intuition for this dissipation result, consider the special case when there is only one possible search period. As in the standard price-setting Bertrand game, each player's payoff maximizing search behavior drives their rival's expected return to zero. The generalized game with more than one possible search period involves the same essential tradeoff, ensuring complete dissipation. This result has far-reaching economic implications for those participating in a treasure hunt, be they pharmaceutical firms, paparazzi, bounty hunters or pirates.

Second, if the players have some ability to coordinate search so as to avoid duplication, the equilibrium in which all rents are dissipated no longer holds; that is, positive expected returns are feasible even when the players can only partially coordinate their search activities. The possibility of coordination may arise between the players through observation. For example it might be evident where miners are moving their equipment, or the direction that a paparazzo is heading; a bounty hunter might have better contacts in one area than another, or might only have a permit to work in a particular jurisdiction. Coordination could also come about through some form of commitment by a player. For example, the sort of experts a research department hires provides a (partial) commitment to the direction of their search. Similarly, pharmaceutical companies might need to make public announcements (in broad terms) about their upcoming clinical trials, and their existing patents will highlight the most obvious place a firm will start looking for the next generation of drug. These coordination devices are, of course, only partial – these commitments can, to a greater or lesser extent, be unwound. Importantly, our modeling suggests that however imperfect, the possibility of *some* coordination creates an environment in which complete dissipation of rents is not possible. This suggests that a third party (government, industry association and so on) could improve on the decentralized market outcome, even if its regulatory technology is quite imperfect.

Duplication with independent search also arises in the model of Fershtman and Rubinstein (1997). They consider a model in which two players search for a single hidden treasure in one of a given set of labeled boxes. First, each player chooses how many costly search units they wish to utilize. Second, each player chooses a random search strategy with which to examine the boxes, where only one box can be examined in any given period by each search unit. While each player knows the total number of boxes their rival can search, all research findings are private information. Their model gives rise to some complementary results to ours. For example, there can be search duplication in equilibrium, when players search previously opened boxes that are empty. Almost the opposite type of coordination failure is also possible: with an asymmetric probability that various boxes contain the treasure, sometimes neither player searches the highest probability box first. The first of these failures does not occur in our model as previous search is observable to all. The second outcome is not possible here either due to our focus on pure strategies. Perhaps the most important similarity is that with independent search rents are completely dissipated in both models. The intuition is also similar: in Fershtman and Rubinstein (1997) each player chooses the number of search units in the first stage of the game such that the other player has a zero expected return; in our paper each searcher chooses an area to investigate each period that drives the other player's return to zero.

Duplication and coordination by duopolists in a dynamic R&D search game is the focus of Chatterjee and Evans (2004). In their model, in each period two competing firms simultaneously choose to research one of two projects, where only one project will eventually be successful (given it has been investigated long enough). As in our model, previous investment is observable and it is common knowledge. They assume, however, that firms can coordinate their search in any given period. In Chatterjee and Evans (2004), only under certain conditions will search be efficient. More typically, the outcome will be inefficient due to too much duplication (reminiscent of our dissipation result above) or too much diversification (in which the firms have too much incentive to investigate separate projects). In particular, if the costs of the two projects are unequal, then there is an equilibrium in which the high-cost project is searched too often, relative to the socially efficient choice. One important difference between their model and ours is that per-period search costs are exogenous in their model, whereas search costs in our model endogenously depend on the search undertaken in any given period. Critically, search endogeneity and lack of coordination in our model leads to a complete dissipation of expected rents, which is not observed in Chatterjee and Evans (2004).

There is a literature that models research contests as rank-order tournaments. In contrast to our paper, this literature analyzes the situation in which there are multiple potential innovations that compete against each other. Some examples recently discussed in the literature include: a 1992 refrigerator competition (see Taylor, 1995), an 1829 steam locomotion tournament (see Fullerton and McAfee, 1999), a 1714 British contest for a method of determining longitude at sea (see Che and Gale, 2003). Within this framework, both Erat and Krishnan (2012) and Konrad (2014) consider the issue of duplication. In Erat and Krishnan (2012), firms simultaneously select which area (or avenue of research) of many clearly delineated areas to search. Each avenue has its own value. In equilibrium, the expected return from choosing any given area is equalized,

[1] Imposing Markov perfection not only makes our analysis simpler, while still being consistent with rationality, but it also makes our results directly comparable to those in the previous literature. See Maskin and Tirole (1988), Bhaskar et al. (2012) and Battaglini et al. (2014) for a general discussion of when the use of SMPE is appropriate.