Competitive Search and Preemptive Exclusion

– Preliminary draft – do not cite without permission

Marc Conte*

June 1, 2007

Abstract

In the context of research and development programs, entry-deterance has manifested itself in preemptive patenting, whereby a monopolist will patent untested research leads to prevent competitors from challenging its position in the market. Our effort studies how the lure of monopoly power impacts firm behavior in the search for a new product prior to the discovery of a success. We model the research and development process as a competitive search through research leads, with the incorporation of competition representing a contribution to the existing literature. We find that, in the presence of competition, a firm may have the incentive to preemptively exclude its competition from searching a portion of the research leads. Such preemptive exclusion increases the probability that a discovery of a success will result in monopoly profits. We discuss the implications of the results for the issue of bioprospecting as a motivation for pharmaceutical firms to contribute to the conservation of biodiversity. Our findings suggest that pharmaceutical firms are willing to enter bioprospecting agreements with host nations, with the caveat that there may be concern about the ability of host nations to adequately protect the intellectual property rights of the pharmaceutical firms.

*Bren School of Environmental Science and Management, 3424 Bren Hall, University of California Santa Barbara, CA 93106-3060. mconte@bren.ucsb.edu

1 Introduction

In his seminal work Capitalism, Socialism and Democracy (1942), Schumpeter argues that the prospect of monopoly power drives investment in research and development, and hence, innovation in a capitalist society. While monopolists price their products to maximize profitability, leading to a loss of consumer surplus, Schumpeter argues that market power can increase societal welfare by extending the suite of products available for consumption. The benefits of monopoly power are known to impact behavior once a firm achieves that position in a market, begging the question: to what extent does the lure of monopoly power impact a firm's behavior as it is competing for that much- coveted position within a given market?

The research and development process is often a competition between multiple firms seeking an innovation that will secure monopoly rents. We develop a theoretical model in which firms engage in a competitive search through research leads, hoping to achieve a monopoly position in the market. Our goal is to identify the impact of competition for monopoly profits associated with research and development innovation on firm behavior prior to the discovery of a useful lead.

Acknowledging competition between innovating firms allows the possibility of preemptive exclusion – one firm may purchase exclusive access to research leads before making a discovery to ensure its monopoly position, should a success exist within the pool of research leads. We study the situation in which the discovery of a new product yields profit that does not impact profits from existing products. We find that the premium associated with monopoly power can make the strategy of preemptive exclusion optimal behavior. In our model, monopoly power is not guaranteed upon discovery of a useful technology, because it is possible that a competing firm could make a discovery from among the pool of remaining leads. This possibility provides value to successful leads that exist within the pool, but which occur later in the sequence of leads than the initial successful lead (such leads have been deemed redundant in the literature).

Our findings have important implications for research and development and patent protection in industries characterized by some degree of competitive search for successes. One relevant example is the pharmaceutical industry, which is characterized by costly research and development efforts that are rewarded with patents for useful discoveries, providing firms with monopoly power in recognition of their successes. Within the pharmaceutical industry, biological prospecting (bioprospecting), the act of combing through natural organisms in search of compounds that might be of use in addressing human diseases, is an example of the research and development process as a competitive search through a pool of research leads. Our finding regarding the incentive for preemptive exclusion, under certain conditions, allows us to comment on the utility of bioprospecting as a conservation tool.

Simpson, Sedjo, and Reid (1996) (SSR) consider the viability of bioprospecting as a conservation tool. Appropriately, SSR describe the search for biochemically-active compounds within the pool of organisms that exist in biologically diverse eco-regions as a search through a pool of research leads. The model that we propose utilizes the framework of a competitive search through a pool of research leads in order to identify the attributes of such pools that will motivate preemptive exclusion.

In addition to providing a framework suitable for answering the question of interest, SSR also offer an assertion worthy of further consideration. In their model of the search process, SSR focus on a firm that enjoys monopoly position in a certain market. In this context, the authors argue that redundant cures are of no value and can therefore be ignored in the profit function of the search-conducting firm. Considering the competitive environment in which such research and development searches occur, it seems possible that the existence of multiple successful leads within a research pool might pose a threat to the ability of any competing firm to enjoy monopoly power in a given market.

As such, although the redundant cures might not be directly valuable to the pioneer discoverer in the form of potential additional profits, possessing rights to these leads might be of value in increasing the probability that the discoverer will be rewarded with monopoly power following a discovery. The results presented below confirm that, under certain conditions, the profit implications of redundant leads are sufficient for a firm engaged in a patent race to preemptively exclude (i.e., before the firm has achieved the monopoly position) its competitor from searching portions of the research pool. It seems that our findings might provide reason to reevaluate the conservation potential of profit-maximizing pharmaceutical firms.

Prior to introducing our model, we present a brief example to highlight the impact of competition on the value of exclusive access to research leads. The influence on firm behavior is partially driven by the negative impact that so-called redundant leads can have on the revenues associated with research and development success. Following this intuitive example, we present a review of the impact of monopoly position on firm behavior. The theoretical model is then introduced and used to identify the impact of a potential monopoly position in a market on firm behavior. The conclusion of the paper provides commentary on the implications of these results regarding the conservation potential of pharmaceutical firms.

2 Illustrative Example

The following example presents the key determinants of firm behavior during a competitive search through a pool of research leads. Consider two firms, A and B, searching for a new product from within a pool of research leads (i.e., the discovery does not impact profits associated with existing outputs). Assume that the research pool consists of two leads. Each firm is equally likely to test a given lead first, meaning that a coin toss determines the search order of each lead. Let R represent the revenues that accrue to a monopolist following success in the research and development process (i.e., the discovery of a success in the search through the research pool). Let R_d represent the revenues that accrue to each firm when both firms make a discovery, where $R_d < \frac{R}{2}$. Each firm faces the same choice before the search of the pool begins: purchase exclusive access to some portion of the existing leads, where the cost of exclusive access is denoted by k, or engage in the search for a useful product by testing the lead for its potential as a marketable product. Let c represent the cost of testing the lead. Let p represent the probability that either lead will be a success.

In the case of two leads, each firm must choose between purchasing exclusive access to both leads, purchasing exclusive access to one lead, or engaging in a competitive search through both research leads. Figure 1 presents an overview of the possible outcomes of such a search process for each of the two firms engaged in the search. The expected profits of the three potential actions facing the firms engaged in this competitive search are presented below.

The expected profits of buying exclusive access to both leads are given by

$$E[\Pi|\text{protect both}] = R(1-(1-p)^2) - 2(c+k) \tag{1}$$

Equation 1 indicates that if a firm excludes its competition from all available research leads, it will reap monopoly profits if a discovery exists in the pool. This result will be achieved so long as both leads in the pool do not fail to yield a marketable product. Another possible strategy for a firm engaged in a competitive search through research leads is to purchase exclusive access to one of the two existing leads. The expected profits of buying exclusive access to one lead are given by

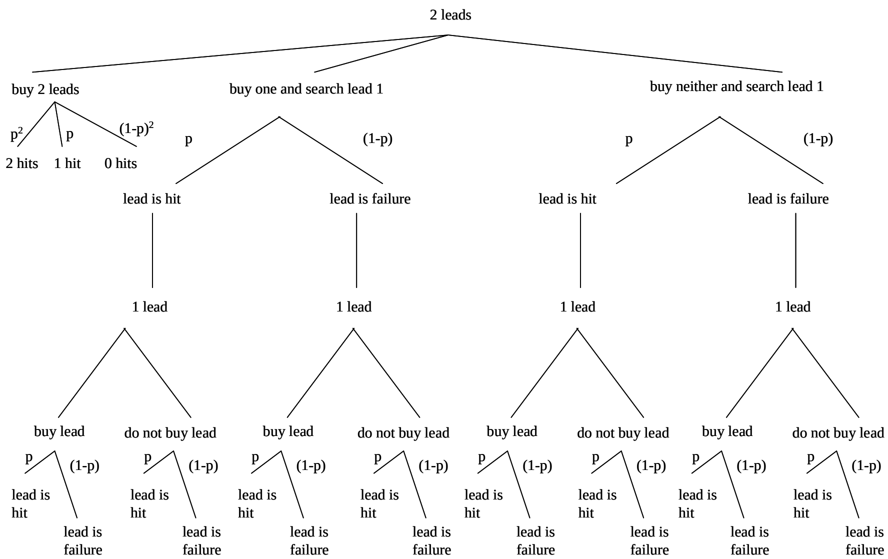

Figure 1: Choice set and associated outcomes for a firm engaged in a competitive search through two research leads.

$$E[\Pi|\text{protect one}] = p(1-p)R + \frac{1}{2}p^2R + \frac{1}{2}p^2R_d + \frac{1}{2}(1-p)pR - 2c - k \tag{2}$$

The first four terms in equation 2 represent the expected revenues associated with all possible combinations of success and failure for two research leads (e.g., success/fail; success/success with one firm discovering both successes; success/success with each frm discovering a success; and fail/success), with the first probability component associated with the lead to which the firm has purchased exclusive access. The final strategy available for a firm engaged in a competitive search through two research leads is to engage in search without purchasing exclusive access to either lead. The expected profits of searching without exclusion are given by

$$E[\Pi|\text{protect none}] = \frac{1}{4}p^2R + \frac{1}{2}p^2R_d + p(1-p)R - 2c \tag{3}$$

In this strategy, the firm does not face the cost of purchasing exclusive access. However, there is a decreased probability of enjoying monopoly power for a given number of successful leads if the firm faces competition when searching each lead.

Without delving into the algebra associated with identifying the optimal behavior for a firm, we are able to identify two components of such a decision that are of importance in determining the viability of purchasing exclusive access to research leads. It is clear that threshold values for k under which preemptive exclusion will obtain are determined by the probability with which any lead will be a hit and the revenue premium associated with a monopoly position in the market relative to a market in which an oligopoly (in this case duopoly) exists. The presence of competition during the search process, as well as the possibility that multiple successes might exist within the research pool, interact to result in different revenues based on how many of the existing successes a single firm possesses. When the discrepancy between monopoly returns and oligopoly revenues is sufficiently great, a profit-maximizing firm will benefit from preemptively excluding its competition from a portion of the research leads.

For example, consider firm A in the illustrative example choosing between excluding its competitor from searching one of the two leads or simply engaging in the competitive search through both leads. In this case, the firm compares the two values presented in equations 2 and 3, leading the firm to choose preemptive exclusion of its competitor from one research lead when

$$k \leq \frac{1}{4}p^2R + \frac{1}{2}p(1-p)R$$

The terms on the right-hand side of the inequality represent the expected revenue premium afforded the firm when it is able to conduct its search process in the absence of competition. Noting that the right-hand side is a positive number, we can state that preemptive exclusion will be optimal behavior, for certain values of k, when a firm is engaged in a competitive search through two research leads.

We see that the presence of competition makes the decision not to search a lead costly for a firm because ignoring it, or treating it as redundant, allows for the possibility that it might be a success that is discovered by its competitor. The discovery by firm B diminishes the rewards associated with firm A's research and development process, providing an incentive for firm A to decrease the probability of such an outcome occurring. The preemptive exclusion of firm B from one or both of the research leads is one strategy that firm A can employ to achieve this objective. The remainder of the paper is spent illustrating the generality of this result and discussing its implications for firms engaged in competitive search through research leads.

3 Monopoly power

Following Schumpeter's analysis of the impact of monopoly power regarding innovation and invention in capitalist economies, a significant portion of the industrial organization literature has attempted to identify the impact of monopoly power on investment in research and development. Many efforts have focused on the research and development investments made by firms that already enjoy monopoly power. While this focus differs from the crux of our effort, understanding the theories that drive post-discovery behavior will make our discussion of pre-discovery behavior more intuitive.

Previous work has demonstrated that monopolists will protect their position in a given market. In the research and development literature, Gilbert and Newbery (1982) show that monopolists will patent leads that have yet to be tested to ensure the persistence of their market power. To be clear, their result is not that the existing monopolist will utilize further discoveries to dominate the market; Gilbert and Newbery find that the later patents may go unused and unlicensed simply to preserve the spoils of monopoly power.

There are a number of factors that can lead to the existence of monopolies, and the one most germane to research and development is patent protection. The competition between firms racing to develop a patentable product has been thoroughly analyzed in the economics literature and has been modeled in various ways to focus on specific aspects of the research and development process. Scherer (1967) studies this problem through the framework of Cournot competition. Loury (1979) uses a static model (i.e., the level of research and development investment at a given firm is identical across time periods) to identify the impacts of uncertainty on the relationship between research and development expenditures and innovative progress. Gilbert and Newbery achieve their result by approaching the patent race as a bidding game, in which the bids represent allocations to research and development. Other notable efforts incorporating game theory into the analysis of the research and development process include Dasgupta and Stiglitz (1980), which identifies the impact of industry structure on research and development expenditure, and Fudenberg et al. (1983), which studies impact of a head-start in the research and development process on the level of competition, and therefore the inefficiency, associated with the research and development process.

A monopolist is able to set market price above the marginal cost of production, enjoying greater profitability than a competitive firm, which provides meaningful incentive for a monopolist to protect its position in the market. Threats to monopoly power can result from regulatory action or the behavior of other firms in the market. The impact of competitors attempting to enter the market on the behavior of the monopolist is relevant to the current discussion regarding the impact of competition on pre-discovery behavior during a search through a pool of research leads.

It is well documented that monopolists will take steps to deter the entrance of potential competitors into their market. The form of entry-deterrence most relevant to our effort has to do with the research and development efforts of a firm that already enjoys market power following a previous research and development success. Gilbert and Newbery use a model of firm behavior to determine how the presence of the patent system impacts the market structure of an industry.

In the Gilbert and Newbery model, a preexisting monopoly is threatened by the potential that a substitute might be discovered during the research and development efforts of a competitor. The monopolist faces the choice of allowing entry to occur or of patenting the substitute technology. In the simple model, Gilbert and Newbery represent the time of innovation as a deterministic function of the expenditures on research and development. This depiction of research and development leads to innovation being attributed to the firm that spends the most money on research and development. In this context, the authors find that the threat to monopoly power posed by a potential entrant is sufficient to incite the monopolist to put forth more money into research and development efforts than the potential entrant so long as entry results in a reduction of total profits below the joint-maximizing level. The authors find that the monopolist can sustain its market power so long as potential entrants rationally expect rivalry to diminish industry profits.

The finding that optimal behavior for an incumbent firm, be it a monopolist or not, might include the patenting of innovative technologies to protect its market position is not merely a theoretical result. Gilbert and Newbery use the term "patent thicket" to describe the patenting of many inventions by a firm, some of which are neither used nor licensed to others, in reference to a 1978 antitrust case between SCM Corporation and Xerox Corporation. And in the context of their model, such behavior is referred to as preemptive patenting, where a firm takes out patents on certain innovations simply to prevent them from being patented by its competitors. In this context, patent thickets are empirical manifestations of the theoretical behavior described by Gilbert and Newbery and Reinganum (1983), lending credibility to the idea that firms will engage in costly activity to protect their market position from potential entrants.

However, since the publication of their work, patent thickets have been applied to highly technical industries in a far less condemnatory manner. The term patent thicket is also used to refer to the group of patented technologies that are related to a single, technologically-complex product. Generally, no single firms holds the patents to the various processes that are relevant to a single product and firms tend to license technologies to competitors with the understanding that such behavior will be reciprocated if necessary. In this case, the term patent thicket merely denotes the fact that technologically intricate products require the aggregation of multiple patented processes for production. Because such processes often have multiple uses, their rights are frequently held by multiple firms and there is a tendency for open licensing, without any of the protective, exclusionary behavior associated with the concept of monopoly protection. Generally, the term patent thicket is used to describe the behavior studied by Gilbert and Newbery, while the use of the term to describe the existence of multiple patented processes associated with a single marketable product tends to be specific to the high-technology sector.

Thus far, research and development has been modeled as a process of investment that results in success after a threshold level of investment has been reached. While this perspective is useful in order to identify the game-theoretic implications of monopoly power on the innovative process, it seems to lack descriptive power in certain aspects of the actual research and development process. For certain industries, the development of new products is related to the identification of a useful technology, such as a compound useful in cancer treatment for the pharmaceutical industry, an idea that can be described in words or on film for authors or screenwriters, or a new pocket of natural gas or petroleum for the oil industry. In these industries, there is no guarantee that investment in research and development will produce any returns, as embodied by the identification of a useful product. As such, modeling the research and development process as a search through potential research leads seems useful. In our model, we analyze the impact of competition on firm behavior during the research and development process, where successes result in the development of products which lack a pre-existing market so that the discovery does not impact the existing products and profits of the firm.

4 The model

We begin our discussion of firm behavior during the research and development process by considering the post-discovery behavior of a firm. We take this approach to defend our decision to model the process as a competitive search through research leads and to confirm that it achieves the same predictions of post-discovery behavior as those reached in models of total research and development expenditures, such as the model presented by Gilbert and Newbery. After identifying the predicted post-discovery behavior, we move on to develop models of pre-discovery behavior for a single firm searching through research leads and for a firm engaged in a competitive search through research leads hoping to achieve monopoly position within a given market. This comparison allows us to comment on the impact of competition on the demand for exclusive access to research leads.

4.1 Post-discovery behavior

Consider a firm engaged in a competitive search, with one other firm, through n research leads, where the probability of a lead being a success, p, is constant across all leads. Let R represent the revenues from discovery of a success that would accrue to a monopolist. We assume that the revenues associated with discovery will be diminished if both firms engaged in the search make a discovery, and refer to an individual firm's share of these revenues as R_d, where $R_d < \frac{R}{2}$.

Let the firm discover a successful lead when testing lead i, meaning that there are $n - i$ leads remaining to be tested. We assume that the discovery-making firm will stop searching through leads following its discovery. Now, we want to determine the optimal action for a firm to take in order to protect its newly-achieved monopoly status. Let k represent the cost that a firm must pay to exclude its competition from searching a given research lead and let this cost be constant across leads. Having paid the cost k, we assume that a firm is able to prevent its competition from testing that lead. Preemptive exclusion is the term that we use to describe a firm's decision to spend k in order to ensure unique access to a research lead before having searched the lead. In choosing to purchase unique access to a portion of the remaining leads following a discovery in lead i, the firm will attempt to maximize the following function, $\Pi_{i,m}$, which describes the profit accruing to a pioneer discoverer following its decision to purchase unique access to m leads,

$$\Pi_{i,m} = -k(m+1) - c - R(1-p)^{(n-i)-m} + R_d(1-(1-p)^{(n-i)-m}) \tag{4}$$

This equation allows the discovery-making firm to determine if it would ever be optimal to prevent its competition from accessing certain portions of the remaining leads. Proposition 1 designates the profit-maximizing actions that the discovery-making firm will take facing the given function, $\Pi_{i,m}$.

Proposition 1 *In competitive search, optimal post-discovery behavior will consist of one of the following actions: protection of the success; protection of all remaining leads; or no protection. The firm will never choose to exclude its competitor from a subset of the remaining leads.*

Proof. The proposition will hold so long as the maximum of $\Pi_{i,m}$ is not found in the interior of the range for m. If the second derivative of the expected profit function with respect to the number of leads to which a firm has purchased exclusive access is non-negative over the entire range of m, then we know that the function will achieve its maximum value at either $m = 1$ or $m = n-i$. So, let us look at the second derivative: $\frac{\partial^2 \Pi_{i,m}}{\partial m^2} = (R-R_d)(1-p)^{(n-i)-m}(\ln(1-p))^2$. The three pieces of the equation are clearly all non-negative. From economic theory, we know that the profit of a monopolist is greater than the total profit in a duopoly market. The monopoly profit is necessarily greater than one firm's share of the total duopoly profit, making the first term positive for all values of m. The middle term will be positive for all values of m so long as $p \geq 0$, and will be zero for all values of m if $p = 0$. Finally, the third term will be positive for all values of m if $p \neq 1$, otherwise it will be equal to zero for all values of m. It is clear that the second derivative will be positive for all values of m for most probabilities (i.e., $0 < p < 1$). Furthermore, if the second derivative is ever equal to zero, then it will be zero over the entire range of m, meaning that the derivative will take a constant value across m, which also precludes a maximum of $\Pi_{i,m}$ occurring unless $m = 1$ or $m = n - i$. ■

Proposition 1 provides support for the concept of "preemptive patenting" suggested by Gilbert and Newbery. Additionally, the results presented in the proposition provide some intuition for the existence of patent thickets. In order to protect its position in a new market, a firm might be willing to patent numerous potential technologies, without expecting to derive direct profits from associated products. Having displayed the ability of the search-based model to predict post-discovery behavior, we are now able to address the focal question of this paper having to do with the pre-discovery behavior of a firm engaged in a competitive search through research leads.

4.2 Pre-discovery behavior

We begin our exploration of the impact of competition on firm behavior during the research and development process prior to the discovery of a success by considering a single firm searching through a pool of leads. Let the pool of research leads contain n separate leads, and let the probability with which any lead contains a useful compound, p, be constant across leads. We assume that the result of a test on any given lead reveals no information about the probability of success for any leads other than the one being tested (i.e., we assume that the probability of success is independently and identically distributed across research leads). Let the cost of searching each lead be constant, c, and let R represent the revenue associated with a discovery. Because there is uncertainty about whether or not a success will occur when testing each research lead, we let θ represent the expected number of leads that will be searched before a discovery is made, which is important in the determination of the overall cost of search. Having identified the individual components, we are able to define the profit function of a single firm searching through a pool of research leads as:

$$E[\Pi] = (1 - (1 - p)^n)R - \theta c \tag{5}$$

We can see clearly that the expected profit of a search increases as the number of leads being searched increases, but that this increase occurs at a decreasing rate (i.e.,$\frac{\partial E[\Pi]}{\partial n} > 0$, $\frac{\partial^2 E[\Pi]}{\partial n^2} < 0$). The above expected profit function introduces two terms that require explanation. θ represents the expected number of searches that will occur given a pool of n leads, each with equal probability of success. We can develop a formula to express the probability of searching all leads given n leads: $P(\text{search n leads}) = (1 - p)^{n-1}$, which follows from the fact that the probability of searching the first lead is one, and each subsequent lead will be searched only if the previous leads are unsuccessful. We see that the expression for the expected number of searches given n remaining leads is the sum of a geometric series: $\theta = \sum ar^j$, where $a = 1$ and $r = (1 - p)$. This result provides us with a well-defined expression for the expected number of searches: $\theta = \frac{1-(1-p)^n}{p}$.

Now, let us consider how such a firm would react to the opportunity to gain exclusive access to a subset of the research leads. Let x represent the number of research leads (out of the n total leads) to which the firm purchases exclusive access and assume that the cost of exclusive access is constant for each lead and represented by k. Because there are no competing firms, exclusive access does not alter the revenues associated with discovery in any of the exclusive leads, so that we can represent the expected profit awaiting the firm in this case as:

$$E[\Pi] = (1 - (1 - p)^n)R - \theta c - xk$$

For a firm operating in the absence of competition, there is no incentive to purchase exclusive access to any of the research leads, because it enjoys de facto exclusive access in the absence of competition. Preemptive exclusion is a costly behavior, which does not provide any benefits to a sole firm engaged in a search for research leads. Additionally, there is no incentive for the firm to search through any research leads following the discovery of a success, because there are no competitors to threaten its monopoly profits by making a discovery.

Proposition 2 *Given discovery of a success on lead i, a firm searching through leads in the absence of competition will not search any of the remaining $n-i$ leads for additional discoveries.*

Proof. Assume that the research pool consists of 2 leads. Let the first lead be a success, so that after searching the first lead, the firm has profits of $\Pi = Rp - c$. Now, assume that the firm searches the second lead. Even if the second lead is a success, under the assumption that the discovery of additional successes does not increase the market demand facing the firm, the firm's profits become $\Pi = Rp - 2c$. It is clear that the firm's profits decrease with continued search following a discovery (i.e., marginal profits are negative for all post-discovery searches). This logic can be applied to research pools of n leads, for all n. A firm engaged in a search in the absence of competition has no incentive to continue searching through the pool of research leads following discovery of the first successful lead. ■

Note that this result is derived in the framework of the SSR model. Approached from this angle, it becomes quite intuitive, under the assumptions of the model, that a single firm searching for new technology does not benefit from the existence of multiple useful technologies. This outcome provides the motivation for the term redundant leads.

We are now ready to introduce competition into the search for useful research leads. Our model incorporates the role of competition in two ways. First, we assume that the presence of multiple firms impacts the probability of any given firm discovering a useful research lead from within the pool. Second, we acknowledge that in the presence of multiple useful research leads, the number of firms competing for monopoly position within a given market impacts the revenues associated with a successful product.

The probability that a firm engaged in a competitive search through research leads will be the first to test a lead will be some function of the number of firms engaged in the search. We specify the form of this function under the assumption that each of the firms searching through the pool of research leads is equally likely to be the first firm to test a lead. This assumption seems readily defensible, although its applicability to the research and development process is dependent on another assumption which might be less realistic: we assume that all firms search through the pool of research leads in the same order (see Appendix for further discussion of this assumption).

Let us now show that the presence of competition decreases the expected value of the profits associated with the discovery of a useful research lead. This impact is driven by the potential that there might be multiple successful leads located within the research pool. In the above discussion, we have deemed additional useful leads in the pool that occur later in the search order than the initial success to be redundant leads. However, our current discussion, which allows for competition in the search process, emphasizes that such a term is inappropriate because the presence of multiple successes can change the profits of research and development success.

In addition to affecting the probability that a given firm will experience a research and development success, the existence of competing firms can impact the profits associated with discovery based on the split of discoveries between a given firm and its competition. When a single firm is engaged in a search through research leads, the benefits of discovery are fixed whether the firm finds one useful lead or multiple useful leads related to the same marketable product, so long as ownership of multiple products does not allow a firm to increase the number of consumers to which it can sell its products (i.e., so long as discoveries are perfect substitutes). This is not the case when multiple firms are engaged in the competitive search through a pool of research leads. Proposition 4 identifies the impact of competition on the revenues associated with research and development success.

Proposition 3 *The presence of competition during a search for successful research leads decreases the expected revenues associated with discovery of a success.*

Proof. We define the revenues for a monopolist associated with a successful search through a pool of research leads as R. For a firm engaged in a competitive search, the revenues associated with discovery depend on the proportion of existing successful leads that a given firm is able to discover. Let h represent the total number of hits, or successes, that exist in a pool of research leads. Let f represent the number of existing successes that are discovered by a firm's competitors. We assume that if $f = 0$, then the revenues associated with discovery for a firm facing competition will be equivalent to the revenues for a monopolist. In fact, we specify the function of h and f that is used to adjust the monopoly revenues of discovery as $\frac{(h-f)}{h}$. Given this specification, it is clear that the rewards of discovery for a firm competing against other firms to discover research successes are less than the rewards of discovery that await a monopolist. ■

The profit function for a firm engaged in a competitive search for marketable products will depend on both h and f. Clearly, h can take on any integer value between 0 and n. It is again elementary to understand that f can take on any integer value between 0 and h. Our model of the expected profits from the research and development effort assumes that a firm's profits associated with discovery are related to the proportion of total successes controlled by that firm. This proportion is given by $\frac{(h-f)}{h}$.

Given an expression for the probability of making a discovery, as well as the manner in which multiple successes can each be of value to a firm engaged in a competitive search through a pool of research leads, we can define the expected profits of engaging in such a search as follows:

$$E[\Pi] = R(\sum_{h=1}^{n}\sum_{f=0}^{h-1}\frac{h-f}{h}\frac{1}{j^{h-f}}p^{h}(1-p)^{n-h}) - nc \tag{6}$$

The formula presented in equation 6 to capture a firm's expected profits from search differs markedly from the formula presented in equation 5, due to the impact of competition on the firm's profits. We discussed above that the presence of multiple firms searching through a pool of research leads will impact the probability that any given firm will be the first to test a particular lead. Similarly, we introduced the idea that the discovery of multiple successful leads would be beneficial to a firm engaged in competitive search due to the impact on revenues associated with competing firms making their own discoveries. The value of making multiple discoveries, which helps a firm approach the monopoly profits associated with research and development success, is also behind the two remaining changes in equation 6 relative to equation 5.

In the case of a single firm engaging in a search through research leads, the benefits of a discovery cannot be impacted by the number of discoveries made by its competition, because it is assumed that such competition does not exist. The fact that a single discovery is sufficient for a firm to enjoy monopoly profits is manifested in the functional form of the probability of discovery. In equation 5, we describe the probability of discovery as the complement of the probability that no successful leads exist in the pool of research leads. This approach indicates that there is no benefit to the firm of discovering more than one success during its research and development process, as there is a cost of searching through additional leads while there is no benefit of making multiple discoveries.

Such logic is inappropriate when considering the benefits of discovery for a firm engaged in a competitive search through research leads. We have assumed that the revenues associated with research and development success are dependent on the number of discoveries made by a firm relative to the total number of discoveries made by all competing firms. More precisely, we have made the assumption that multiple existing successes in a pool of research leads would result in the development of products that would be perfect substitutes for each other.[1] The number of discoveries made by a firm, rather than the probability that at least a single success exists within the pool for research products, is of interest in determining the expected profits associated with a competitive search through research leads. As such, equation 6 accounts for the possibility of any possible number of successful research leads existing in the pool as well as the probability that a single firm possesses all possible combinations of the existing successes in order to determine the expected revenues of competitive search.

The final difference between equations 5 and 6 has to do with the number of leads that a firm will search through in the presence or absence of competition. When a firm is able to search through a pool of research leads without fear of competitors challenging its market power through discoveries of their own, we assume that the number of leads tested is a function of the probability that any given lead will be a success. As a single success is sufficient to

[1] While this may seem to be an overly restrictive assumption, examples from the pharmaceutical industry with aspirin and ibuprofen offering nearly identical results as well as the competition between Viagra, Levitra, and Cialis, lend a sense of realism to this assumption.

ensure monopoly profits, we develop the expected number of leads searched by assuming that subsequent leads are tested only if a discovery has yet to be made. This logic is not appropriate when the firm is racing against competitors to search through the pool of research leads. In the face of competition, a firm is not guaranteed to hold a monopoly position following the discovery of a single successful research lead. However, the firm is able to approach this monopoly position by increasing its number of discoveries toward the total number of successful leads that exist in the pool. This distinction emphasizes the direct and indirect value of multiple successes that has been previously discounted in the literature through the interpretation of such research leads as redundant successes. It also leads us to Proposition 4:

Proposition 4 *When the cost of search lies below a certain threshold ($c < p\frac{R}{jn}$), the presence of competition induces a firm to test all research leads, which would not occur if it were operating in the absence of competition.*

Proof. We consider the case in which a firm has the least incentive to continue testing following discovery of a success in order to prove proposition 4. Let there be a pool of n research leads and let the search of the first $n-1$ leads, which are all successes, have occurred. Further, let a single firm have been the first to test each of the $n-1$ successes so that it possesses all of the successes with one lead remaining. If the firm does not engage in the search of the last lead, its expected profits are $E[\Pi|\text{search } n-1 \text{ leads}] = (1-p)R + p\frac{n-1}{n}R - (n-1)c$. If the firm does search the last lead, its expected profits are $E[\Pi|\text{search } n \text{ leads}] = (1-p)R + \frac{p}{j}\frac{n-1}{n}R + \frac{p}{j}R - nc$. The profits of searching the last lead are greater than not searching it so long as $c < p\frac{R}{jn}$. It seems that this case represents the situation in which the firm has the least to gain from searching through all leads, so that as long as the cost of search lies below the above threshold, competition is sufficient to induce a firm to search through all research leads in the pool. ■

Acknowledging that multiple successes can be of value during competitive search motivates the possibility that a firm might be willing to prevent its competition from searching a portion of the research leads. In order to approach the monopoly rewards of research and development success that exist in the absence of competition, a firm might take action to gain exclusive access to a portion of the research leads. Such a strategy would serve to increase the probability that it would hold a monopoly position in the market if successful leads were to exist in the pool of research leads.

Before pursuing the impacts of such action analytically, let us first define the actions that a firm could take, in practice, to afford the unique opportunity to search through a pool of research leads. We take such an action to be defined by the costly exclusion of others from a potentially rewarding subset of the research leads. In the oil industry, such an action might include the leasing of access to areas that might include pools of petroleum and natural gas, before any discovery regarding the presence of oil or natural gas has occurred. In the pharmaceutical industry, such an action might involve a firm paying a host country for exclusive access to a subset of natural organisms before any compounds found within the organisms in the subset has been confirmed to be biochemically responsive to a given human disease (e.g., entering into a bioprospecting agreement). Such an action in the high-technology industry might include the patenting of several technological processes before the marketable uses of such processes has been determined (note, this is a clear pre-discovery parallel to the post-discovery behavior studied by Gilbert and Newbery, which those authors termed preemptive patenting).

Let us consider that it is possible for a firm engaged in a competitive search to pursue a strategy of preemptive exclusion, where we define preemptive exclusion to mean pre-discovery behavior of a firm that limits the pool of research leads to which its competitors have access. Now, let x represent the number of research leads that the firm preemptively excludes its competitors from searching, at a cost of k per lead. Trivially, x must take on some integer value between 0 and n, inclusive. The firm faces no competition during its search of the x leads to which it has secured unique access; however, the revenues that will follow from discoveries made in this pool of leads are dependent on the outcome of the competitive search through the remaining $n - x$ research leads.

We have identified the potential revenues associated with a pre-discovery strategy of preemptive exclusion. Given this understanding, we are able to determine the firm's expected profit function from engaging in a competitive search with preemptive exclusion. The appropriate formula is:

$$E[\Pi] = R(\sum_{h=1}^{n-x}\sum_{f=0}^{h-1}\frac{1}{h+\gamma}((h-f)\frac{1}{j^{h-f}}p^h(1-p)^{n-x-h} + \sum_{i=1}^{x} ip^i(1-p)^{x-i}) - nc - xk \qquad (7)$$

Any successes that exist within the x leads that the firm chooses to preemptively exclude its competitors from searching, will be discovered by the firm. However, the revenues associated with discovery will depend on the percentage of total hits controlled by the firm. Therefore, we incorporate the pool of leads to which a firm has exclusive access in two ways.

First, because the revenues associated with discovery will depend on the outcome of the competitive search through the $n - x$ remaining leads, we need to identify the number of successes that will exist in the exclusive pool, in order to determine the expected profits of such a strategy. We represent the number of successes as a binomial random variable γ over the x leads isolated through preemptive exclusion. This choice is based on the fact that the probability of any given lead being a success is a Bernoulli random variable with probability of success p, so that the number of successes in a pool of x leads is a binomial random variable.

Second, we need to determine the probability with which each possible number of discoveries from the exclusive pool occurs. Lacking competition during the search through these leads, the firm will discover all successful leads that exist in the pool. As such, we can model the possible number of successes using the unmodified formula for a Bernoulli process.

Having identified the expected profits associated with a strategy of preemptive exclusion, we must now determine whether or not a profit-maximizing firm engaged in a competitive search through a pool of research leads would ever choose to preemptively exclude its competition from a portion of the research leads in order to increase the profits associated with discovery. By asking this question, we will be able to identify the impact of competition on the value of exclusive access to the marginal research lead. This point of interest leads us to the following proposition:

Proposition 5 *Over a certain range of values for the cost of exclusion, the optimal behavior for a profit-maximizing firm involved in a competitive search through research leads will involve the preemptive exclusion of its competition from a portion of the leads in the research pool.*

Proof. To prove propsition 5, we compare the expected profits that await a firm when $x = 0$ and when $x = 1$. Clearly, when $x = 0$, the firm's expected profits are as described in equation 6, which we will describe here as $\phi - nc$. When $x = 1$, the firms expected profits are

$$\frac{1}{1-p}\phi + R(\sum_{h=1}^{n-1}\sum_{f=0}^{h-1}\frac{1}{h+1}((h-f)\frac{1}{j^{h-f}}p^h(1-p)^{n-h-1} + p) - nc - k$$

and we see that the profits of preemptive exclusion are greater than those under competitive search when $k \leq \frac{p}{1-p}\phi + R(\sum_{h=1}^{n-1}\sum_{f=0}^{h-1}\frac{1}{h+1}((h-f)\frac{1}{j^{h-f}}p^h(1-p)^{n-h-1} + p)$. ■

The intuition behind the result described in Proposition 6 was first presented in the simple example of two firms searching through a pool of two research leads. The value of preemptive exclusion comes from the resulting decreased likelihood that a firm's competition will make a discovery from the reduced pool of research leads to which it has access. By decreasing the likelihood of competitor discovery, a firm is able to increase the rewards that it will receive from success in its own program of research and development, increasing its incentive to invest in such a program.

It must be mentioned that the discussion of preemptive exclusion thus far has proceeded in order to demonstrate that firms engaged in competitive search have an incentive to engage in such behavior. This discussion has not aimed to suggest that this strategy will increase the profits of the search for research leads in practice; the propositions above have identified incentives for any firm engaged in such competitive search, meaning that all firms searching through the pool would have incentives to behave in this way. Presumably, the outcome would be a bidding war to enjoy preemptive exclusion, meaning that the profits of such behavior would be dissipated. Nevertheless, that outcome does not alter the key insight afforded by this analysis: the incentive to preemptively exclude competitors from a portion of the research pool exists. It is this finding, which differs from previous studies that is of greatest interest and is of relevance to the issue of bioprospecting as a means of conservation.

The incorporation of competition into the search of research leads, which results in the viability of preemptive exclusion, increases the value of the marginal research lead to a company. In the presence of competition, if a firm does not search a lead, it not only misses out on the potential discovery of a success, it also decreases the value of any other successes that it may find by allowing the lead to be searched by its competition. The impact of competition on the marginal value of a research lead, which has not been addressed in previous studies that model the research and development process as a search through research leads, seems relevant to the process of bioprospecting. As such, following an update on the state of the world regarding bioprospecting practices, we reconsider the conservation potential of pharmaceutical firms in the next section.

5 Competitive search and bioprospecting

International recognition of the importance of biodiversity has led environmental groups to suggest that pharmaceutical firms might play a role in the conservation of tropical ecosystems, where much of the world's biodiversity is found, due to the role played by natural compounds in the research and development of new pharmaceutical products. SSR discounts such a notion, arguing that the value of the marginal species in some of the most biologically-diverse regions of the world is insufficient to prompt pharmaceutical firms to spend money preventing habitat destruction in those regions. Our effort re-evaluates the viability of bioprospecting as a conservation mechanism by viewing bioprospecting as a race for monopoly power and concludes that pharmaceutical firms could contribute to the conservation of biodiversity.

The incorporation of competition into the research and development framework, modeled as a search through research leads, provides insight into the pre-discovery behavior of firms. Such a model provides a realistic version of pharmaceutical research and development efforts and allows for the possibility that firms could gain through the conservation of biodiversity. Our theoretical findings suggest that the demand for exclusive access to natural compounds may exist.

In our theoretical model, firms are able to preemptively exclude their competitors from searching segments of the research pool by purchasing exclusive access to research leads. This framework is analogous to the existing practice of pharmaceutical firms signing bioprospecting agreements with host nations, where a host nation is the country whose territory encompasses an area of great biological diversity. A bioprospecting agreement is essentially a contract stipulating that a pharmaceutical firm will pay a mutually-agreed upon sum to a host nation for the privilege of gaining exclusive access to a specified subset of native organisms. Then, it seems reasonable to interpret bioprospecting agreements as a form of preemptive exclusion, whereby a pharmaceutical firm will pay for unique access to a number of species, ideally preventing its competition from searching those leads.

Our model of firm behavior during a competitive search through research leads is consistent with the existence of bioprospecting agreements in practice, an outcome that is not supported when the search process is modeled in the absence of competition. While previous studies have mentioned the 1991 bioprospecting agreement signed between Merck and INBio, the National Biodiversity Institute of Costa Rica, it is often described as a goodwill act and the dearth of other existing bioprospecting agreements has been used to support the argument that pharmaceutical firms have nothing to gain from biodiversity conservation.

In fact, there are numerous examples of existing bioprospecting agreements; however, the details of the agreements are not readily revealed. The INBio web page notes that the institute entered into 21 different bioprospecting agreements with 18 different international pharmaceutical firms in a ten-year period from 1991 to 2001. Although this is by no means a comprehensive record of existing bioprospecting agreements, this practical evidence of pharmaceutical firms purchasing exclusive access to research leads indicates that there is demand for such agreements. Furthermore, the formation of bioprospecting agreements is behavior that can be predicted by our model of firm behavior during a competitive search through research leads.

Within our model, a firm is able to guarantee exclusive access to a research lead by paying a cost of k. Implicitly, we are assuming that this costly action ensures that the firm has a property right (intellectual or otherwise) to that lead. In practice, it may not be that the formation of bioprospecting agreements will be sufficient to ensure complete property-right protection. Accordingly, it is essential to be familiar with the guiding principles of bioprospecting agreements in order to determine if and how such agreements differ from our model of exclusive access.

In 1992, the Convention on Biological Diversity (CBD) developed guidelines for bioprospecting agreements to ensure that host nations would be able to share in the profits associated with successful product development. The CBD aimed to guarantee that host nations would receive just compensation for protecting their native biodiversity. The principle objective of the CBD was the conservation of biological diversity, as well as equitable benefit-sharing of products derived from organisms, including a call for contracts to emphasize training of host peoples in the practice of sample collection and compound testing (Article 1). The CBD simultaneously recognized the importance of intellectual property rights and allowed for their transfer to the prospecting firm conditional on the host nation's approval: host nations acknowledged that pharmaceutical firms would need their intellectual property rights to be defensible within host nations in order to enjoy the monopoly profits of drug-discovery that justify their significant research and development programs.

The protection of intellectual property rights is essential for pharmaceutical firms to hold monopoly positions following research and development success. In 1995, the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) further developed the ability of firms to protect intellectual property internationally. The World Trade Organization (WTO) encouraged all member countries to develop national legislation that supported the goals put forth in the TRIPS agreement as quickly as possible. The TRIPS agreement highlights the concern from the pharmaceutical firms that their willingness to enter into exclusive use contracts with host-nation organizations might not result in monopoly power upon the discovery of a useful compound. This concern is based on fears that the host-nation might be unable to control access to the species covered by the agreement or that the legal environment in the host-nation might not be sufficient to support patents on compounds identified as useful. While the vast majority of host countries have taken this step, the credibility of such an action is not uniform across countries. As such, pharmaceutical firms have taken to obtaining samples from botanical gardens in industrialized countries, where they can be assured that their discoveries will enjoy meaningful legal protection. Such actions might be interpreted as a signal that pharmaceutical firms are unwilling to participate in more costly bioprospecting agreements with host countries; however, the anecdotal evidence from Costa Rica, mentioned above shows a significant number of bioprospecting agreements since the CBD. This evidence, and the seemingly unique nature of the legal infrastructure and credibility of the government in Costa Rica relative to other host nations, might also suggest that the pharmaceutical firms depend on the unique access to research leads for success in their industry, which is ensured by credible property right legislation and enforcement in host countries.

Additional support for the argument that there is demand for unique access but concern about enforceability of intellectual property rights is that more recent research efforts have focused on the structure of existing bioprospecting agreements and the host-nation characteristics that impact this structure. Mulholland and Wilman (2003) present a theoretical model depicting the process of contract formation and discuss its predictive ability in the context of certain existing agreements. Sampath (2005) identifies optimal property rights structures and institutions for regulating bioprospecting and uses these features as predictors of success or failure for several existing agreements. The shift in the bioprospecting literature to a focus on contract formation and an evaluation of existing agreements reaffirms the belief that demand for bioprospecting agreements, and the exclusive access to these natural compounds that they guarantee, exists.

Mulholland and Wilman explore the formation of bioprospecting agreements in the context of a dynamic principal-agent model so as to identify components of agreements that are essential if bioprospecting is to be of any use in the efforts to conserve biodiversity. The authors stress that appropriate institutions must exist for host nations to turn the potential pharmaceutical value of *in situ* biodiversity into incentives for conservation as well as returns for both the pharmaceutical firms and the host nation itself. Generally speaking, their results indicate that property rights, of the intellectual and more tangible varieties, will play an important role in determining the impact of bioprospecting on the effort to conserve biodiversity.

Sampath reviews many of the fundamental elements of bioprospecting in order to identify the institutions that must exist for equitable sharing of the potential gains from bioprospecting. She notes that regardless of the efforts made at the international level, including the text developed during the CBD and the TRIPS agreement, the most critical determinants of the continued existence of bioprospecting agreements will be national laws. And she argues that the definition of property rights regarding genetic resources and the knowledge that has been accrued over the long-run by traditional societies through laws at the national level that also delineate the appropriate rules of contracting will be essential for bioprospecting to occur in a manner satisfactory to both prospecting firms and host nations.

The efforts of Mulholland and Wilman and Sampath reinforce the importance of well-defined and credibly-enforced property rights for the potential profits associated with new pharmaceutical products to promote conservation efforts in host countries. As underscored by our theoretical model of firm behavior during a competitive search, the protection of intellectual property rights is of fundamental importance in order for pharmaceutical firms to enter into bioprospecting agreements with host countries. However, in order to achieve the conservation of biodiversity, the property rights to the value of the *in situ* biodiversity is almost of equal importance. Without clear assurance that their efforts to conserve will result in financial reward for themselves, local decision-makers will not feel as though they are residual claimants to the fruits of their efforts and the key cog in the conservation machine will be missing.

6 Conclusion

We have found that monopoly power, which has been previously shown to impact the behavior of firms holding such a position, can also influence the behavior of firms who are competing to hold such a position. The revenue premium associated with holding a monopoly position is shown to influence both the pre-discovery and post-discovery behavior of firms engaged in a competitive search through a pool of research leads. This finding is primarily a result of the threat to monopoly revenues associated with discovery posed by the potential presence of multiple successful leads within a single research pool.

In previous efforts to model the value of the marginal research lead during a search through research leads, it has been assumed that the discovery of a successful research lead will unambiguously result in monopoly profits. In this context, there is no value attached to the presence of successful leads subsequent to the pioneer success, a result that we implicitly obtained in Proposition 2 above. In addition to other necessary conditions, this result is contingent on the assumption that if a firm does not test a research lead, it vanishes from existence. Such an assumption allows multiple successes that exist in the pool of leads to be deemed redundant. However, it seems more natural to assume that if a given firm does not test a research lead, it will remain in the pool of research leads, where it might be tested by another firm.

The introduction of competition into the framework of the search for a successful research lead assigns value to each of the successes that exist in the pool, transforming these subsequent successes from valueless redundancies into reward-threatening substitutes. Realizing that the benefits of discovery will be diminished if a firm's competition is able to identify a discovery from the remaining pool of research leads provides incentives for the firm to decrease the probability of such a counter-discovery occurring. Under certain conditions, the increased marginal value of any given research lead is then significant enough to prompt the strategy of preemptive exclusion.

This finding, because the assumed conditions sufficiently parallel the process whereby pharmaceutical firms search for useful compounds from natural sources, seems poised to offer a meaningful contribution to the debate about the conservation potential associated with bioprospecting. It is clear that multiple pharmaceutical firms are engaged in the search for novel organic compounds for use in the drug-development process[2]; therefore, it seems unreasonable to assume that any discovery in the process will unambiguously result in a monopoly position in the resulting drug market. Of further relevance is the fact that bioprospecting agreements are clear examples of preemptive exclusion, whereby the firms are paying host nations for exclusive access to a portion of the relevant research leads in return for the nation's assurance that any potential discoveries will be granted meaningful intellectual property right protection. In effect, these results seem to provide both theoretical and anecdotal evidence that there is demand from pharmaceutical firms for the opportunity to preemptively exclude their competitors from portions of the research lead pool.

While this paper has offered evidence that there is demand amongst pharmaceutical firms for exclusive access to research leads, it has also implicitly suggested that there is not an adequate

[2] The empirical support for this statement is provided by the fact that Eli Lilly and Company, Bristol-Myers Squibb, and Merck & Company, have each entered into bioprospecting agreements with INBio. This is by no means a comprehensive list of existing bioprospecting agreements, though it seems sufficient to support the above statement.

supply of such access being offered by host nations. Within the model, a firm is willing to spend money to exclude its competition from a segment of research leads because this costly activity ensures that its competition will not have access to those leads, increasing its probability of enjoying monopoly power upon the discovery of a success. In practice, as Sampath indicates, the legal environment in many of the host nations is insufficient to offer pharmaceutical firms the level of intellectual property rights that they desire. This fact signals that host nations may need to take strides to modify their legal environment before they will be able to share in the benefits from bioprospecting and before pharmaceutical firms will be able to contribute to the conservation of biodiversity.

7 Appendix

The assumption that the pool of research leads is searched in the same order by all firms competing for monopoly power in the market is made for computational simplicity, otherwise the probability of any research lead yielding a successful product would vary based on whether or not the item had been searched by competitors. It seems unlikely that firms competing in a research development program would happen to search potential leads in the exact same order. However, it does seem reasonable that competitive firms with the same information might choose to order the leads in the same manner based on the probability of success (i.e., firms would test the items with the highest probability of success first). Our assumption relies on the logic of symmetric information while maintaining a constant probability of success across leads.

Rausser and Small (2000) study the impact of sorting potential research leads on the value of the marginal lead in a response to the SSR finding that the potential value of organisms with regard to pharmaceutical products is not sufficient for pharmaceutical firms to subsidize conservation. Rausser and Small motivate their research effort by commenting on the value of information in the search process, noting that in practice searches are not conducted by proceeding through objects in a random order. Rather, search is conducted efficiently, with the efficiency stemming from an ordering of the objects to be searched by their prospect of providing a reward.

Using their model of search through a sorted pool of leads, Rausser and Small determine that, under certain conditions, the information rents associated with identifying different probabilities of success amongst the pool of leads can be sufficient to impact development and conservation decisions. The authors note that when the number of leads to be searched and the profits from research and development are both large, the incentives for conservation arise almost uniquely from the magnitude of the search costs and the quality of information available to sort the leads. Having identified theoretical support for the use of pharmaceutical firms as proponents of conservation, Rausser and Small reconsider the attempt made by SSR to estimate the value of natural compounds as inputs in the drug-development process. By adding the information rents that accompany a sorted search process into the valuation of areas of high biodiversity, Rausser and Small develop per hectare values for areas with high numbers of endemic species that are two orders of magnitude larger than those estimated by SSR.

It should be noted that work by Costello and Ward (2005) re-evaluates the findings of Rausser and Small and attributes the difference in valuation of biodiversity hotspots to an assumption regarding the appropriate metric of biodiversity. Despite this caveat regarding the findings of their research effort, the model developed by Rausser and Small provides some intuition for our approach regarding the assumption of an identical search order across firms. We acknowledge that this assumption may not be intuitive, but we do not believe that relaxing it would impact our findings.

References

Costello, C. J. and M. Ward. Search, bioprospecting, and biodiversity conservation. *Journal of Environmental Economics & Management* 52(3): 615-626.

Dasgupta, P. and J. Stiglitz. Uncertainty, industrial structure, and the speed of R&D. *The Bell Journal of Economics* 11(1): 1-28, 1980.

Fudenberg, D., R. Gilbert, J. Stiglitz, and J. Tirole. Preemption, leap-frogging, and competition in Patent Races. *European Economic Review* 22(1): 3-31, 1983.

Gilbert, R. J. and D. M. G. Newbery. Preemptive Patenting and the Persistence of Monopoly. *The American Economic Review* 72(3): 514-526, 1982.

Loury, G. C. Market Structure and Innovation. *The Quarterly Journal of Economics* 93(3): 395-410, 1979.

Mulholland, D. M. and E. A. Wilman. Bioprospecting and biodiversity contracts. *Environment and Development Economics* 8: 417-435, 2003.

National Biodiversity Institute Home Page. Copyright 2007. National Biodiversity Institute, Costa Rica. 9 Oct. 2006. <http://www.inbio.ac.cr/pdf/acuerdos%20industria.pdf>.

Rausser, G. C. and A. A. Small. Valuing Research Leads: Bioprospecting and the Conservation of Genetic Resources. *Journal of Political Economy* 108(1): 173-206, 2000.

Reinganum, J. F. Uncertain Innovation and the Persistence of Monopoly. *The American Economic Review* 73(4): 741-748.

Sampath, P. G. Regulating Bioprospecting: Institutions for Drug Research, Access and Benefit-Sharing. United Nations University Press, New York, NY, 2005.

Scherer, F. M. Research and Development Resource Allocation under Rivalry. *The Quarterly Journal of Economics* 81(3): 359-394, 1967.

Schumpeter, J. Capitalism, Socialism, and Democracy. Harper Brothers, New York, NY, 1942.

Simpson, D. R., R. A. Sedjo, and J. W. Reid. Valuing Biodiversity for Use in Pharmaceutical Research. *Journal of Political Economy* 104(1): 163-185, 1996.