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Searching for a partner on the internet and analogous decision-making problems

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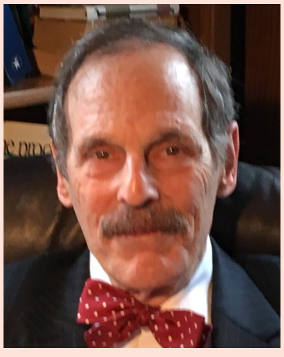
Abstract: Information technologies supporting online dating create an enormous expansion of the population of potential partners. However, such a large population offers too much information, too many choices, too many potential (and potentially unsatisfying) partners. The importance of conducting a search efficiently is imperative. This paper applies the economic theory of decision-making under uncertainty to analyze the optimizing behavior of rational adults who use internet dating sites. The analysis applies expected utility to a randomly distributed population of candidates. The main result derives conditions that must be satisfied by a searcher who allocates his time efficiently. The result is based, in part, on an assumption that the behavior of the searcher is guided by his recognition of adverse selection and "cheap talk." The analytical results can be applied to search-and-action scenarios totally unrelated to a search for a romantic partner. These include such diverse scenarios as the deployment of military drones searching for a target or a search for a home or a search for an employment opportunity.

Subjects: Social Sciences; Behavioral Sciences; Economic Theory & Philosophy; Microeconomics

Keywords: efficient allocation of time to search-and-action; expected utility; internet dating; adverse selection and cheap talk



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Edmund H. Mantell is a professor of Economics and Finance at the Lubin School of Business, Pace University, New York. He delivers lectures in those subjects to MBA candidates. His main research interest addresses the question of how rational individuals can make reasonably good decisions in conditions of unavoidable uncertainty. The research reported in this paper is related to that area because of the inherent uncertainty a man or a woman must contend with when utilizing the internet to conduct a search for a durable romantic relationship.

PUBLIC INTEREST STATEMENT

The proliferation of so-called dating websites is evidence of a technology-driven demand for personal relationships. For example, in year 2013 it was estimated there were 380 billion people using internet-based technologies to find romantic partners. This paper addresses the question of how a search can be carried out efficiently. The paper proceeds from the assumption that the searcher's time is a scarce resource. He or she must decide how much total time per week the searcher is willing to devote to search and action. An efficient searcher (of either sex) must decide two questions: (1) What fraction the total search time ought to be allocated to surfing the web to identify a potential partner (or partners) and (2) What fraction of the total time ought to be allocated to cultivating personal relationships with the potential partners the search discovers. The paper applies the tools of economics to allocate time efficiently.

> [A man should marry] *first, for virtue; secondly, for wit; thirdly, for beauty; and fourthly, for money.*
>
> Samuel Johnson, LLD[1]

1. Introduction

The proliferation of dating websites is evidence of consumer demand for personal relationships, even if initiating them requires payment to a third-party matchmaker. The expansion of Internet dating can be seen as a response to the defects of the traditional market mechanism. Ariely (2010, p. 215) has commented that the dating market for single people (the coordination mechanism that helps them find partners efficiently) has long been "one of the most egregious market failures in Western society." This paper develops a theoretical analysis of the behavior of rational users of dating websites.

The introductory paragraph in a recent paper by Hitsch, Hortaçsu, and Ariely (2010) lists a few of the macro-market statistics characterizing the population of dating-site users. A subset of the population of users is estimated to be approximately 380 billion.[2] The Hitsch paper carried out an ingeniously conceived empirical study of the efficiency of online dating. Using a novel data-set obtained from a major online dating service, the authors applied the Gale–Shapley algorithm to predict stable matches.[3] They concluded, *inter alia*, that the predicted matches were similar to the actual matches achieved by the dating site, and that the actual matches were achieved efficiently. However, the definition of "efficient" employed by those authors was based on their finding that:

> … the observed and predicted attribute correlations and differences are largely similar [which] suggests that the online dating market achieves an approximately efficient matching within the class of stable matches.[4]

That statement means that users of online dating sites are generally successful in finding potential matches who display the reciprocating personal attributes that both parties are seeking.

The Hitsch paper does not address a question of economic efficiency confronting virtually all users of online dating sites, namely how should an individual allocate the search time he or she devotes to online searching for a potential partner. The salience of this question was vividly expressed by a recent essay appearing in the popular press.[5]

> Online dating generates a spectrum of reactions: exhilaration, fatigue, inspiration, fury … The typical American spends more of her life single than married, which means she's likely to invest even more time searching for romance online. Is there a way to do it more effectively, with less stress?[6]

The importance of conducting a search efficiently is recognized by all users of online dating sites as well as by academics who study the socioeconomics of online dating. However, there does not appear to be any published research that directly addresses the question of how a rational consumer can allocate his or her search time efficiently. The theory developed in this paper suggests an answer to that question. In the discussions following the male pronoun is used, but all the analytical results derived here are equally applicable to women.

It is assumed that a man using an online dating service has a utility function defined on his idiosyncratic requirements (whatever those may be).

It is assumed the man has exogenously determined how much of his time to allocate to a dating site. He must then decide how much of that time to allocate between two distinct activities: (1) searching the site for potential matches and (2) making overture(s) to the potential matches his search discovered.

The model developed in this paper is one-sided matching. This paper makes no attempt to analyze the strategic behavior of a searcher after he has identified a potential match. However, the theory does explain how he can conduct his search for a potential match efficiently.

The theory developed in this paper also applies to many other kinds of search-and-action scenarios, some of which are suggested in the concluding remarks.

2. Synoptic description of the search and action characteristics of online dating[7]

When a searcher first registers with an internet dating service, he or she must respond to questions in an online survey conducted by the service. Some of the surveys are quite extensive and probing. The service uses the registrant's responses to create for him what is called a "profile." A profile is a web page displaying the registrant's responses to the survey. Online dating services do not verify the information the registrants provide. The failure to verify their information encourages registrants to engage in what economists call "cheap talk." The search strategy implications of cheap talk are discussed in Section 4.2.

The registrants' profiles appear on the service's website and can be accessed by any other user registered with that service, sometimes by any person with internet connectivity. The registrant discloses various demographic, socioeconomic, personal, and physical information, e.g. age, sex, education, height, weight, children, occupation, and income. Most dating services require the registrant to indicate his motivation for registering: e.g. to find a long-term relationship or a traveling companion. Many registrants include one or more photographs of themselves (or their pets or their children) in their profile. After registering, users can browse, search, and interact with other registrants.

In the language of online marketing, the process of online dating described above corresponds to the model of a *marketing funnel*. The funnel is described below[8]:

(1) *Impressions*: The *impressions* consist of a subpopulation of women's profiles found by a man when he searches the entire population of women's profiles posted online. The impressions represent the subset of the women's posting which are regarded by the man as appealing enough (to him) to constitute reasonable candidates for *click-throughs*. For example, the impressions might consist of a subset of women with reasonable propinquity with respect to the man.

(2) *Click-throughs*: These women's profiles are a subset of the *impressions*. The women they depict are the recipients of the man's first communication(s). The first is usually made by an e-mail message transmitted through the intermediary of the online dating service or by an invitation to chat, also sent via the dating service.[9] The purpose of the click-through is to gather additional information about the woman behind the impression. For example, the man may try to elicit information not disclosed on the woman's profile. The additional information allows the man to determine whether he wants to meet the woman he clicked on.

(3) *Conversions:* These are the women represented by a sub-subpopulation of *click-throughs.* The members of this sub-subpopulation have two properties: (a) The information gathered by the man during the click-through phase has given him an incentive to meet the woman (or women) he clicked on and (b) Women may respond to the man's click-through by signaling that they are amenable to a face-to-face meeting or a preliminary phone conversation with him.[10] It is reasonable to assume that such meetings actually occur if both parties are willing. Thus, a conversion activity or set of activities will provide the man with enough additional information to allow him to make a decision as to whether he wants to try to cultivate a durable relationship with the woman (or women) he converted.[11] This paper employs the terminology of the marketing funnel. The click-through and conversion activities are referred to as "action."

3. The theory of internet search and action

The scarcity issue in this paper is manifested as the problem of how a man should to allocate his only scarce resource, namely a fixed amount of time. He can allocate it in two time-consuming activities: (1) the activity of searching for a suitable woman (i.e. the impressions) and (2) the activity of cultivating a relationship with a woman (or women) his search discovers (i.e. the click-throughs and conversions). Time is a scarce resource in this paper because it is assumed to be fixed by the man himself. The problem he faces is how to use that scarce resource efficiently.

The efficient allocation of a fixed search time is not a trivial question. Millions of users of online dating sites are not only spending their money on subscriptions to the services, but are also investing considerable time. One estimate suggests that users allocate an average of 22 min each time they visit an online dating site (Mitchell, 2009). Another study suggests that users of dating sites allocate 12 h weekly to online dating activity (Frost, Chance, Norton, & Ariely, 2008). Considering that there are millions of users of online dating sites worldwide and that their numbers are increasing, the aggregate temporal opportunity costs must be large. This fact argues strongly that a user's time should be allocated efficiently, assuming the user is really trying to find a match and is not simply entertaining himself with no intention of acting.

A recently published book, Gottlieb (2010), written by a woman, expressed the attitude of typical users this way: "I was still stuck in the online dating mentality—that if you don't like something about one guy, there's a seemingly infinite supply of new dating candidates lined up."[12]

The "on-line dating mentality" described above is common among users of online dating sites; those users regard the population of potential candidates as practically infinite. The obvious implication is that users of dating websites do not recognize any scarcity of potential matches. Their belief (rightly or wrongly) is that the elimination of a potential match does not reduce the potential matches remaining in the population. That belief motivates a fundamental assumption of this paper: When a man conducts a search on a dating site, it is reasonable to characterize his activity as a random search through a practically infinite population of women's postings.

Each woman identifies herself by a set of attributes appearing in her profile. It is assumed the attributes are randomly distributed among the postings. The man may regard some (or many) of the attributes as irrelevant to his search. However, it is assumed he identifies a set of *m* attributes defining the field of his search. The set is symbolized by:

$$\langle X \rangle \equiv \langle x_1, x_2, \ldots x_m \rangle$$

A randomly selected woman in the population of registrants can be uniquely characterized by the values of $\langle X \rangle$ appearing in her profile. It is assumed the searching man assigns numerical values to qualitative attributes, e.g. eye color. The numerical values he assigns are manifestations of the utility yield by those attributes.

It is assumed all the attributes in $\langle X \rangle$ are non-negative continuous random variables. For example, distance from the man's locality. The attributes are distributed in the gross population of registrants as a subset of sample space(s) defined by the online survey conducted by the service.

The random variables in $\langle X \rangle$ are governed by a multivariate continuous c.d.f. symbolized by $F(X)$. It is assumed the distribution F is known or can be estimated by the searcher. It is assumed to be differentiable. The density function is symbolized by $f(X)$.

The searcher's utility function is assumed to be continuously differentiable with respect to every attribute. It is symbolized by:

$$U = U(X)$$

The mathematical properties of $U(X)$ are the usual; $\partial U / \partial x_i > 0$, for all x_i.

The total time the searcher decides to allocate to his internet dating activity is symbolized by T. The units of T are hours per month or some other convenient temporal metric. The searcher's time must be allocated between the portion of it he devotes to searching the web-based dating service(s) for impressions and the portion he devotes to action (i.e. click-throughs and conversions).

The fraction of the total time the searcher allocates to his search of the population of profiles is symbolized by $0 < \theta < 1$. Thus, the total time allocated exclusively to searching for impressions is θT. It follows that the total time he allocates to action is $(1 - \theta)T$.

It is assumed the average search time required to discover an impression is a constant, symbolized by T_s. The average time required for the searcher to act on a previously discovered impression is also assumed to be a constant, symbolized by T_a. As a practical matter, T_a is generally much larger than T_s, although the inequality is not a requirement of the theory.

The cost to the searcher of conducting the search consists of the sum of two components: (1) the direct cost of registering with an online dating service and (2) the opportunity cost of the time allocated to the search. The direct cost imposed by the online service is a fixed dollar amount for a fixed period of time; e.g. $25 per month. Some web-based services do not impose any fee. A characteristic of all online dating services is that the marginal monetary cost of a search is zero if it is carried out within the registration period. The opportunity cost of time will vary idiosyncratically among individuals in the population.

It is obvious that the total time individual men are willing to allocate to a search and action to find a partner is randomly distributed among the population of men. For a specific man, T may be one hour per week and for a different man T may be 10 h per week. However, it is assumed each man will define T as being equal to 1 unit of time, and for him that one unit is fixed. That definition focuses the searcher's attention exclusively on the allocation of T between search and action. Thus, the average number of impressions that a man discovers in the unit time interval is θ / T_s. The average number of impressions he can act on in the unit time interval is $(1 - \theta)/T_a$.

Of the impressions the man finds, the expected utility of those acted on is symbolized by $\bar{U}$. These definitions allow a calculation of the expected payoff of the impressions a man discovers in the unit time interval:

$$\bar{\pi} = \frac{\bar{U}}{T_a}(1 - \theta) \tag{1}$$

4. Recognizing and managing adverse selection and cheap talk online

A recent publication by Best and Delmege (2012) carried out an empirical study of the behavior of users of online dating sites. Commenting on the use of online dating sites to search for a partner, the authors of the study put it this way (p. 253):

> … filtering strategies are adopted spontaneously and refined conscientiously by participants … strategies of searching profile commentary … are important. Efficiency becomes increasingly more important as the process (of website search) continues, as does … learning to manipulate the surveillance and architectural controls of the site itself.

This section suggests how a man might conduct his search so as to mitigate the disappointments he expects to experience because of adverse selection and cheap talk. The basic idea is that the searcher will apply the user-controlled filters provided by the online dating service to identify a subpopulation of impressions.

4.1. Adverse selection in online dating sites

Adverse selection is manifested in online dating. Even users without training in economics or risk management recognize that much relevant information about registrants' postings is hidden from searchers; the information is not disclosed or it is purposefully misrepresented. Moreover, some users of online dating services (or their friends and family) entertain the belief that there is a stigma attaching to those who use them.[13] Donn and Sherman (2002) conducted a study in which they examined the attitudes concerning online dating websites. They found that impressions of such sites were relatively negative. A more recent study by Anderson (2005, p. 521) observed: "*Online interpersonal relationships, particularly romantic relationships, carry the stigma of being something of a 'talk show phenomena.'(sic)"* Attitudes about online dating include the views of people who perceive online relationships as tenuous connections formed by desperate people embarking on their last attempt at a romantic interlude Donn and Sherman (2002), as well as views of those who see online relationships as associated with deviant (and sometimes illegal) behaviors and practices, such as pornography and cybersex.[14]

To the extent that a man believes, rightly or wrongly, that it is those women who are the least appealing who are the most likely to register with a dating service, his belief constitutes a text-book paradigm of the problem presented by adverse selection, at least insofar as he is concerned.[15] The relevant point is not that adverse selection is necessarily found in online dating; the point is that many users believe that it is and they adjust their searches to accommodate for this belief.

4.2. Cheap talk in online dating sites

Probably more salient to the difficulties of online dating than adverse selection is the problem posed by cheap talk. Cheap talk is defined as communication that is (1) costless (there are no out of pocket costs), (2) non-binding (it does not limit strategic choices in any way), and (3) ex ante unverifiable (it cannot be verified by a third party, like a court).[16]

A registrant in a dating site can engage in cheap talk with impunity, at least up to the time of a face-to-face meeting. Misrepresentation and outright falsification are thought to be endemic to online dating websites. One publication (Whitty, 2007) described registrants of online dating sites as "… quite strategic in their online presentation." The author of that publication did not distinguish between what she called "strategic misrepresentation" and outright lies. Empirical studies have documented lying on dating websites. These include Hancock, Toma, and Ellison (2007) and Rudder (2010).[17] This kind of social behavior is an example of the economic theory of cheap talk.

All users of online dating sites recognize the problem posed by cheap talk. Cheap-talk models address the question of how much information can be credibly transmitted when communication is direct and costless. When a single informed expert who is known to be biased gives information or advice to a decision-maker, only noisy information can be credibly transmitted. The more biased the expert is, the noisier the information. For example, it is a common complaint among male users of online dating sites that many women post photographs that are unrepresentative of themselves (to put it mildly) and many women report their ages and their weights inaccurately. Women complain that men inaccurately report their heights and misrepresent their incomes, *inter alia.*

The men and women who post information on their profiles are, *ipso facto*, informed experts about their own attributes. There can be little doubt that such "experts" are biased. A man recognizes that women who post profiles have an incentive to exaggerate what they believe to be their attractive qualities. He, of course, is presented with exactly the same incentive. This incentive is self-reinforcing. The ubiquity of cheap talk appearing in online dating sites is explained by Oyer (2014, p. 42): "In some situations, you have almost no choice but to lie or exaggerate about yourself because, given that other people lie and exaggerate, people discount what you say."

4.3. Managing the risks of adverse selection and cheap talk

Of the population of women discoverable by a man, it is assumed he is willing click through only on those whose disclosed attributes satisfy him, at least when taken at face value. Some of those attributes are objectively measureable: e.g. age, height, education, geographic distance from the searcher. Other attributes may be intensely subjective: e.g. physical attractiveness displayed in registrants' photographs and/or the eloquence expressed in their written narratives.

It is assumed the searcher understands his own preferences well enough to assign non-negative numerical values to each attribute in his personal set of criteria. Thus, if the amenities of the site's user controls permit, the searcher can apply those controls to filter through the population. There is empirical support for this proposition. Best and Delmege (2012, p. 238) remark:

> Most interesting in our findings is that participants quickly become increasingly technologically literate, allowing them to manipulate code-based features of the site to give them an edge in filtering through potential candidates.

What those authors mean by an "edge" consists of an efficient filter defined by the man and made effective by the controls the site permits the user to deploy.

The set $\langle X \rangle$ can be partitioned by the searcher. From a behavioral point of view, it is assumed the searching man will not click through on a woman's profile unless each of her attributes exceeds a lower bound the man assigns to a subset of the attributes he identifies in the partition. This is the strategy he will apply to mitigate (but not eliminate) the risks of adverse selection and cheap talk. The set of lower bounds is referred to as the minimal set. It contains $n \leq m$ attributes. The elements of the minimal set are arbitrarily ordered as the first n enumerated attributes in $\langle X \rangle$. The partitioned set of minimal attributes defined by the searcher is symbolized as:

$$\langle X_{\text{min}} \rangle \equiv \langle x_{1,\text{min}}, x_{2,\text{min}}, \ \cdots \ x_{n,\text{min}} \rangle$$

The implication of the man's recognition of adverse selection and the ubiquity of cheap talk is that his definition of the minimal set will raise the bar to discount for the misrepresentations he expects to encounter on the women's postings. It is assumed the man understands the characteristics of his utility function well enough to identify a reasonably realistic set of parameters in X_{min}.[18] The elements of the minimal set are defined in such a way that the lower bounds must be satisfied.

The search strategy of defining a minimal set is restrictive because it precludes trade-offs among the minimal attributes. However, it defines the elements of the minimal set in such a way as to include only the searcher's "must have" requirements. For example, elements of the minimal set might be a requirement of geographical propinquity or age or level of formal education. The searcher may look for other attributes in the complement to the minimal set, represented by $\langle x_{n+1}, x_{n+2}, \cdots x_m \rangle$. In the complement subset the searcher will accept trade-offs among attributes; e.g. eye color and height.

Any registrant's profile whose attributes satisfy the minimal set is defined as an *impression*. It is obvious that a definition of a minimal set of attributes will not filter out profiles where registrants misrepresent or fail to disclose relevant attributes. However, a reasonable definition of a minimal set will enable the searcher to use his search time more efficiently and thereby lessen the opportunity cost of his search. A user's realistic assessment of his (or her) own market value should inform the user's definition of a minimal set. Moreover, the definition will increase the likelihood of discovering an impression that actually meets the searcher's minimal set. It is when impressions are converted (if ever) that the problems posed by adverse selection and cheap talk can be mitigated or perhaps even eliminated.

The expected number of impressions the searcher can click through in the unit time interval will be a function of the number of impressions he expects to discover. The latter expectation is calculated as:

$$\text{Expected number of discovered impressions:} = \frac{\theta}{T_s}\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} f(X)\prod_{i=1}^{n} dx_i \tag{2}$$

For fixed values of $\langle X_{\min}\rangle$, T_s, and T_a the number of click-throughs is:

$$\frac{1-\theta}{T_a} = \frac{\theta}{T_s}\left[1 - F\left(X_{\min}\right)\right] \tag{3}$$

Equation (3) shows that the expected number of impressions the searcher will act on can be expressed as a function of the parameters θ, T_s, and T_a. After the searcher assigns values to the components of $\langle X_{\min}\rangle$, the expected utility of the impressions acted on, symbolized by $\bar{U}$, can be found from the definitional Equation (3)[19]:

$$\bar{U} = \frac{\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i}{1 - F\left(X_{\min}\right)} \tag{4}$$

From Equation (3) one can write the fraction of the impressions the searcher acts on as:

$$\frac{T_s}{T_a}\frac{1-\theta}{\theta} = 1 - F(X_{\min}) \tag{5}$$

Substituting the left-hand side of (5) into the right-hand side of (4), the expected utility of the impressions acted on can be written as:

$$\bar{U} = \frac{\theta}{1-\theta}\frac{T_a}{T_s}\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i \tag{6}$$

Substituting the right-hand side of (6) into (1), we have the expected pay-off of the impressions acted on:

$$\bar{\pi} = \frac{\theta}{T_s}\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i \tag{7}$$

5. Deciding the allocation of time between search and action

Actual user behavior in online dating markets is not represented exactly by the model described in this paper. However, the model captures the basic mechanisms that are manifested in online dating. Specifically, the dichotomized search-and-action model developed here shares with the Adachi (2003) the assumption that users of online dating sites have a reasonably unbiased understanding of their own market value. This understanding influences their idiosyncratic definition of an appealing set of attributes desired in a partner.

Recent empirical findings by Hitsch et al. (2010) imply that accounting for the costs of a dichotomized search-and-action model need not include an accounting for the psychic cost of sending an introductory initial e-mail that is rejected or ignored. Their paper states:

> Thus, even if unattractive men (or women) take the cost of rejection into account, this perceived cost is not large enough such that the net expected benefit of hearing back from a very attractive mate would be less than the net expected benefit of hearing back from a less attractive mate. These results suggest that there are no significant costs of e-mailing attractive users, and, consequently, that strategic behavior is of little importance in online dating.

Equation (7) is the searcher's objective function. He must find an optimal value of θ, symbolized by θ^*, that maximizes $\bar{\pi}$ for fixed values of T_s, T_a, and $\langle X_{min} \rangle$. That is to say, if the average search time to discover an acceptable impression and the average search time allocated to acting on that impression are both fixed, the searcher must decide what fraction of his total time should be allocated to each activity.

The usual technique is applied for finding an extreme value of a differentiable function: The derivative of Equation (7) with respect to θ, is set equal to zero and solved for the value of θ^*. Mathematical Appendix A displays the differentiation and the solution value of θ^*:

$$\theta^* = \frac{\bar{U}^* - U(X_{\text{min}})}{\bar{U}^*} \tag{8}$$

where $\bar{U}^*$ symbolizes the expected utility of the impressions generated by the optimal value of θ.

It is obvious that the optimal allocation of search time in Equation (8) satisfies the inequality boundary requirements: $0 < \theta^* < 1$.

Equation (8) implies

$$1 - \theta^* = \frac{U(X_{\text{min}})}{\bar{U}^*} \tag{9}$$

The mathematical result appearing in Equation (8) can be expressed as a behavioral proposition.

PROPOSITION 1 Of the subset of online registrants satisfying the minimally acceptable attributes specified by the searcher, the optimal fraction of time he allocates to acting on one or more members of that subset is the ratio of the marginal utility acted on to the expected utility acted on.

Equation (8) implies that the optimal fraction of time allocated to search (and hence to action) is an explicit function only of the expected utility of the impressions discovered and the utility of the minimal impression. This result can be expressed behaviorally.

Suppose the total search time, previously symbolized by T, is increased by the amount ΔT. The incremental search time can be allocated by the searcher exclusively to searching for impressions, i.e. an increase of θ. An increase in the time allocated to searching for impressions can be expected to replace marginal impressions with those closer to the average impression in the subpopulation. In the terminology of the marketing funnel, there will be more women entering the funnel at its mouth. In less clinical language, a man will discover a larger subpopulation of more appealing (to him) women.

Alternatively, if the incremental search time is allocated exclusively to acting on the impressions previously discovered, $1 - \theta$ is increased. This result will increase the number of impressions acted upon at the margin. In the language of the marketing funnel, a man will click through and attempt to convert the subpopulation of women he previously found during his search of the dating website.

The rational man will recognize that the optimal allocation of his incremental time must equate the benefits from his marginal search and the benefits of his marginal action. This equality implies Equation (8).

It is remarkable, and perhaps counterintuitive, that the optimal value of the search parameter is independent of the average search time required to discover an impression, as well as of the average search time required for the searcher to act on an impression. Equation (5) demonstrates that the value of θ is a function of the ratio of the average search times, T_s/T_a. As mentioned previously, this ratio will usually be much smaller than 1.

6. Illustration of an efficient decision in a special case

The results in (8) and (9) can be exemplified by a simple (not to say simplistic) special case. The case is based on a special property of the searcher's utility function and on the joint probability density function defined over the attributes he seeks.

First, it is assumed that the searcher's utility is a weighted average of the attributes in $\langle X_{\min}\rangle$:

$$U(X) = \sum_{i=1}^{n} w_i x_i \quad \text{where } w_i \geq 0 \text{ for all } i \tag{10}$$

A famous literary example of a weighted connubial utility function appears in the epigraph to this paper.[20]

Second, it is assumed that the probability density functions governing the elements of $\langle X\rangle$ are statistically independent exponential distributions with distinct parameters:

$$f\left(x_i;\lambda_i\right) = \lambda_i e^{-\lambda_i x_i} \quad \text{for } i = 1, 2, \ldots n \tag{11}$$

Mathematical Appendix B shows that the optimal value for the action parameter in this special case is:

$$1 - \theta^* = \frac{U(X_{\min})}{\bar{U}^*} = \frac{\sum_{i=1}^{n} w_i x_{i,\min} e^{-\sum \lambda_i x_{i,\min}}}{\sum_{i=1}^{n} w_i \left[x_{i,\min} + \frac{1}{\lambda_i}\right] e^{-\lambda_i x_{i,\min}}} \tag{12}$$

In the ultra-special case where the searcher prescribes a singular attribute, namely x, the parameter $1 - \theta^*$ in Equation (12) reduces to[21]:

$$1 - \theta^* = \frac{x_{\min}}{x_{\min} + \frac{1}{\lambda}} \tag{13}$$

The expected value of an exponentially distributed random variable is the reciprocal of its parameter. Thus, Equation (13) can be written as Equation (14):

$$1 - \theta^* = \frac{x_{\min}}{x_{\min} + E(x)} \tag{14}$$

It is obvious that: $\lim_{x_{\min}\to\infty} 1 - \theta^* = 1$

The limiting property of Equation (14) can be expressed as Proposition 2.

PROPOSITION 2 If the searcher's utility function is risk-neutral and univariate, and if the singular attribute he searches for is a random variable governed by an exponential distribution, then the fraction of the total search time he allocates to acting on the opportunities he discovers approaches 1 as the lower boundary of the desired attribute increases.

Proposition 2 is amenable to a common sense construction. If a risk-neutral man refines his search to discover only women who display a single attribute, and if that attribute is exponentially distributed among the women registrants, then nearly all of his time will be allocated to clicking through and converting the women his search discovers.

7. Application of the decision-making theory to scenarios other than internet dating

The theory developed in this paper can be applied in a wide variety of search-and-action scenarios unrelated to the search for a romantic partner. The possibilities discussed below exemplify the diversity of the theory's applications, and each presents manifestations of adverse selection and cheap talk.

7.1. The United States Army deploys weaponized, remotely piloted aircraft, often referred to by the press as drones. The weaponized drones search remote areas of Afghanistan (and other places) for potential military targets satisfying a set of predetermined attributes. If the pilot (sitting at a control console in Nevada, USA) identifies such a target and receives approval from an authority, the drone's weapon is triggered. The search-and-destroy characteristics of this kind of military operation correspond very closely to characteristics of the theoretical model of online dating. In this military scenario, the application of the theory should take into account the marginal cost of triggering the weapon as well as the costs of the two types of errors: (1) the cost(s) of attacking a harmless target and (2) the cost(s) of ignoring a potentially dangerous target. In the drone scenario, the ratio T_s/T_a is much larger than one. Because the pilot is searching for targets to destroy, the adverse selection in this scenario consists of a preponderance of apparently benign sightings.

7.2. A potential buyer of a home conducts an internet search of real estate websites for a property displaying the amenities he wants. He can apply Equations (8) and (9) to determine the optimal allocation of his time to the search and to conversions. If his search turns up many listed properties within his minimal set, he can apply an optimal-stopping rule to convert a property.

7.3. A lawyer representing a client in litigation seeks to retain an expert witness to render testimony. The lawyer will often conduct a search of internet websites that specialize in listing and categorizing expert witnesses. Rules of evidence and the trial judge will preclude the lawyer from offering duplicative expert testimony. Thus, he can retain only one expert for a litigated issue. If the lawyer's search discovers many candidates who satisfy his nominal requirements, the lawyer applies an optimal-stopping rule to convert the singular best candidate.

7.4. An unemployed person can use the internet to search for a job. In the past 20 years, there has been a rapid proliferation of websites posting employment opportunities for almost every legitimate occupation in almost every geographic region. The conduct of a job-seeker in this kind of search-and-action scenario may be mathematically indistinguishable from the conduct of searchers in online dating. If a job-seeker conducts his search in a population where there is a very large number of potential jobs he can fill, a rejection by an employer will not significantly reduce the employment opportunities for his continued search.

8. Concluding remarks

At its most general level, the theory developed in this paper suggests how a decision-maker can allocate his time efficiently between two related but distinct activities: (1) searching for actionable opportunities in a large population characterized by diverse attributes that are randomly distributed and (2) acting on the most appealing of the opportunities found in the search. An efficient allocation of time between search and action seems to be especially important in an environment characterized by a very large population of unknown opportunities where a decision-maker must select some for definite action.

Proposition 1 has many applications because of its generality. The derivation of the proposition does not rely on special assumptions about the properties of the decision-maker's utility function or the probability density governing the random distribution of the salient characteristics in the population.

Proposition 2 relies on special assumptions pertaining to the decision-maker's utility function and probability density function governing the sample space of opportunities. However, the four exemplary applications described in Section 7 conform reasonably closely to those special assumptions.

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Notes

1. Hawkins (1842).
2. *Match.com*, a wholly owned subsidiary of Ticketmaster and a part of USA Networks Interactive, published a 2013 *factsheet* claiming 1.9 million "core subscribers." Another service, *JDate*, has about 350,000 registered users. See Coleman and Bahnan (2009). Yahoo.com claims almost 380 million visitors per month to their online dating site. Whitty (2009) and Kale, King, and Spence (2009) state that more than half a billion users across the globe have availed themselves of online dating services.
3. The authors in the paper by Hitsch et al. define a "match" as an event where two users exchanged information indicating that they were about to meet offline. The authors expressly acknowledged that their data-set did not allow them to observe whether two users who met online went on an actual date or eventually got married.
4. Hitsch et al. (2010).
5. Ansari and Klinenberg (2015). This essay is written in a somewhat satirical tone. The first-named author is a professional comedian.
6. The first clause in the second sentence seems dubious to this author. I presume the authors drafted it for its comedic value. However, to the extent that many married women live decades longer than their husbands or their ex-husbands, and they may not remarry, the clause might be true.
7. The description in Section 2 is a synopsis of the description appearing in Hitsch et al. (2010).
8. For an extensive discussion of the multiple phases of internet dating, the reader may consult Whitty (2009). Her essay describes five distinct phases of online dating.
9. Online dating services strongly discourage and may prevent registrants from posting their personal e-mail addresses or any other personal contact information.
10. Some of the women who are the subjects of the click-throughs will reject a meeting or will ignore the click-through. The conversions are those women who are willing to meet the man who clicked on their profiles.
11. A "durable" relationship is not precisely defined in the context of this paper. I use the term to suggest any consensual relationship going beyond the initial face-to-face meeting.
12. Gottlieb (2010, p. 91).
13. See, for example, Jennifer Egan, "Love in the Time of No Time" *New York Times Magazine*, November 23, 2003: "*A fair number of people still feel a stigma about online dating, ranging from the waning belief that it's a dangerous refuge for the desperate and unsavory to the milder but still unappealing notion that it's a public bazaar for the sort of people that thrive on selling themselves.*" See also Wildermuth (2004).
14. See Durkin and Bryant (1995) and Kantrowitz, King, and Rosenberg (1994).
15. There is a nice explanation for the lay reader of how adverse selection is manifested in online dating sites in the recently published book by Oyer (2014).
16. See Farrell and Rabin (1996).
17. Oyer (2014, p. 33) states that there is a dating website in South Korea that requires participants to submit a copy of a national registration form, diplomas, and proof of employment, which the site uses to verify age, marital history, parents' marital status, education, and type of job.
18. The assumption that a user of an online dating site understands what he wants in the way of a partner is challenged by Ariely (2008). In the book by Gottlieb (2010, p. 112), the author reproduces part of her interview with Ariely. Here, is a synopsis of Ariely's remarks: "The idea that people know what they want is quite ludicrous … The less you know about a potential mate before you meet, the better … Knowing too much about a person sight unseen makes it harder to become interested in him …".
19. Technically speaking, Equation (3) defines the conditional expected utility, i.e. the expected utility on the truncated sample space $E[U(X)|\langle X\rangle \geq \langle X_{\min}\rangle]$.
20. The author of this paper acknowledges the impossibility that a man will have the ability to discern a woman's virtue (whatever that may mean) based on the information appearing in her profile.
21. In the special case of a singular attribute, the superfluous subscript is omitted.

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Mathematical Appendix A

From Equation (1) we have:

$$\frac{d\bar{\pi}}{d\theta} = -\frac{\bar{U}}{T_a} + \left(\frac{1-\theta}{T_a}\right)\frac{d\bar{U}}{d\theta} \tag{A1}$$

Setting the derivative equal to zero and solving for the optimal value of θ^*, we have:

$$\bar{U}^* = \left(1-\theta^*\right)\frac{d\bar{U}^*}{d\theta^*} \tag{A2}$$

Equation (A2) represents the expected utility of acting on the impressions found in the search when the parameter θ is assigned its optimal value.

Equation (6) can be differentiated with respect to θ:

$$\begin{aligned}\frac{d\bar{U}}{d\theta} &= \left(\frac{T_a}{T_s}\right)\left[\frac{d}{d\theta}\left(\frac{\theta}{1-\theta}\right)\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i + \left(\frac{\theta}{1-\theta}\right)\frac{d}{d\theta}\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i\right] \\ &= \left(\frac{T_a}{T_s}\right)\left[\frac{1}{(1-\theta)^2}\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i - \left(\frac{\theta}{1-\theta}\right)U(X_{\min})f(X_{\min})\right]\end{aligned} \tag{A3}$$

The first term on the right side of (A3) can be rewritten, pursuant to Equation (6):

$$\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)\prod_{i=1}^{n} dx_i = U\,\frac{1-\theta}{\theta}\,\frac{T_s}{T_a} \tag{A4}$$

Differentiating Equation (5) with respect to θ we have:

$$\frac{T_s}{T_a}\frac{1}{\theta^2} = f\left(X_{\min}\right) \tag{A5}$$

Substituting (A4) and (A5) into (A3) and simplifying by canceling factors, we have the resulting equation:

$$\frac{d\bar{U}^*}{d\theta^*} = \frac{\bar{U}^*}{\theta^*(1-\theta^*)} - \frac{U\left(X_{\min}\right)}{\theta^*\left(1-\theta^*\right)} = \frac{\bar{U}^* - U\left(X_{\min}\right)}{\theta^*\left(1-\theta^*\right)} \tag{A6}$$

Combining (A6) with (A2), we have:

$$\bar{U}^* = \frac{\bar{U}^* - U(X_{\min})}{\theta^*} \tag{A7}$$

Equation (A7) leads immediately to the optimal value of θ^* appearing in Equation (8).

Mathematical Appendix B

The assumption of statistical independence implies that the joint probability density function of the elements of $\langle X \rangle$ is:

$$f(X;\lambda_1,\lambda_2,\dots\lambda_m) = \left[\prod_{i=1}^{m}\lambda_i\right] e^{-\sum_{i=1}^{m}\lambda_i x_i} \tag{B1}$$

The probability that an arbitrary discovery will possess attributes satisfying the conditions imposed by the minimal set is:

$$Prob(x_1 > x_{1,\min},\ \dots . x_n > x_{n,\min}) = 1 - F(X_{\min}) = e^{-\sum_{i=1}^{n}\lambda_i x_{i,\min}} \tag{B2}$$

The numerator of the expected utility in Equation (4) in the special case is:

$$\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)dx_1\cdots dx_n = \int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty}\sum_{i=1}^{n} w_i x_i\left[\prod_{i=1}^{n}\lambda_i\right]e^{-\sum_{i}^{n}\lambda_i x_i}\prod_{i=1}^{n}dx_i \tag{B3}$$

The statistical independence of the random variables in X permit the expression on the right-hand side of Equation (B3) to resolve as:

$$\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)dx_1\cdots dx_n = \sum_{i=1}^{n}\int_{x_{i,\min}}^{\infty} w_i x_i\ \lambda_i e^{-\lambda_i x_i}\ dx_i \tag{B4}$$

It is a straightforward calculation to show that the definite integral in the summand in B4 is:

$$\int_{x_{i,\min}}^{\infty} x_i\ \lambda_i e^{-\lambda_i x_i}\ dx_i = \left[x_{i,\min} + \frac{1}{\lambda_i}\right] e^{-\lambda_i x_{i,\min}} \tag{B5}$$

Carrying out the integration on the right-hand side of B4 and summing, we have:

$$\int_{x_{n,\min}}^{\infty}\cdots\int_{x_{1,\min}}^{\infty} U(X)f(X)dx_1\cdots dx_n = \sum_{i=1}^{n} w_i\left[x_{i,\min} + \frac{1}{\lambda_i}\right]e^{-\lambda_i x_{i,\min}} \tag{B6}$$

The general definitional equation for $\bar{U}$ given in (4) can be expressed in this case as:

$$\bar{U}^* = \frac{\sum_{i=1}^{n} w_i\left[x_{i,\min} + \frac{1}{\lambda_i}\right]e^{-\lambda_i x_{i,\min}}}{e^{-\sum_{i=1}^{n}\lambda_i x_{i,\min}}} \tag{B7}$$

Substituting Equation (B7) into ratio (9) to compute $1 - \theta$ leads directly to Equation (12).