Chapter 27

SEARCH

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Contents

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1. Search theory

"One should hardly have to tell academicians that information is a valuable resource: knowledge *is* power. And yet it occupies a slum dwelling in the town of economics." So wrote George Stigler in his 1961 paper introducing search theory. Things have changed. The erstwhile slum-dweller has prospered: information issues are now to be found at the most elite and prestigious of economics addresses. Search theory has provided a simple and remarkably robust laboratory which economic theorists have used to examine a wide variety of questions about the acquisition of information. Early work on search, inspired by the seminal work of Stigler (1961), modeled the individual's searching decisions and drew inferences about the value of information and the nature of frictional unemployment. More recent work, building on sequential-bargaining analysis (reviewed in the Chapter by Binmore, Osborne, and Rubinstein in this Handbook), has focused on the interactions among searching agents and has deepened our understanding of the nature and meaning of competition.

Section 2 of this survey analyzes the classical search problem: the optimal search rule for an individual who can, for a fixed and constant cost, take a random sample from a distribution $F(\ )$ of economic opportunities. This standard formulation of the search problem raises several important questions. The opportunity to search from $F(\ )$ is of economic value; what determines who gets this opportunity? To the best of our knowledge, economic theorists have addressed this problem only tangentially: several papers [Lucas and Prescott (1974) and Mortenson (1976) are examples] have discussed how agents allocate themselves across different markets where each market is, from the point of view of the agent, characterized by a distribution $F(\ )$ of economic opportunities; David (1973) has used a similar model to analyze labor migration.

The bulk of recent work on search has focused on two other questions. The first is about the determinants of the distribution $F(\ )$. The second concerns the rules under which search and sampling take place and the way these affect the division of surplus between the different sides of a market. A simple example underscores both of these questions. Consider the market for a single good that is sold at several stores. Assume that all stores have identical cost structures and produce the item at a net cost of \$1; all buyers place the same value, \$2, on the item and incur of cost of k to visit any store. When a potential customer walks into a store, therefore, there is a potential surplus of \$1 to be split between them. How will this surplus be divided? Diamond (1971) analyzed this problem, using the following argument. Suppose that the rules of the game are such that stores quote prices to buyers (that is, each seller is a Stackelberg leader with respect to the buyers). Then buyers decide whether or not to accept this offer. If they decline the offer, then they walk out of the store and search again. Diamond argued that, when buyers' search costs are positive, the only equilibrium of this process has all stores charging \$2 and appropriating all the surplus. The monopoly price rules no matter how many sellers there are. The argument is simple. Suppose, to the contrary, that there is an equilibrium in which some store is charging less than \$2. Let p be the lowest price charged by any store. A store charging p can increase its profits by raising its price slightly; if it raises its price by less than k, no customer who enters the store will refuse to buy. A customer who walks out must pay a search cost of k; he will save less than k by leaving and searching again. Thus, if the store raises its price by this small amount it will make the same number of sales. However, its profits from each sale will increase. It follows that there is no equilibrium in which any store charges less than \$2. This argument is quite general: it continues to hold (with obvious modifications) if customers differ in their valuations and in their search costs, as long as all customers have search costs bounded away from zero. Also, the argument is symmetric: if we allowed customers rather than stores to make the first offer, gave stores no choice but to accept or reject this offer, and postulated that it cost stores something (in inventory costs) to wait for another customer then the market would clear at a price of \$1.

How can a nondegenerate price distribution $F(\ )$ be sustained? Are there models of markets in which distributions of economic opportunities are part of a Nash equilibrium? At first blush it is difficult to understand how this could come to be; it is clear that if agents on one side of a market are the same, they will in general face the same problem and solve it in the same way. Thus identical stores will charge the same prices of all their customers and the distribution $F(\ )$ will be degenerate, as in Diamond's example. A nondegenerate distribution can be part of an equilibrium only if it somehow turns out that profit is maximized at several different prices or if agents are different. Section 3 below surveys some attempts to solve this problem. This work establishes that nondegenerate distributions can be part of an equilibrium in many models in which all participants behave optimally.

Diamond's example makes two further points. First, the details of who gets to make an offer matters; and, second, to analyze these situations completely bargaining theory is needed. In Section 4 we discuss how search theory and bargaining theory have been used to analyze these questions. The marriage of search theory and bargaining theory has produced some of the more interesting recent economic theory. This research has illuminated such diverse and important topics as the nature of the competitive mechanism and the possible impact of externalities and multiple equilibria on macroeconomic performance.

2. Stopping rules

The classical search problem is as follows. By paying a fixed cost, k, the searcher gains the right to take a random sample (of size one) from a distribution $F(\ )$. The objects drawn from $F(\ )$ – we shall call them opportunities – are of value to the searcher. Typical examples are a job (with a given expected lifetime income),[1] the right to buy some desired object at a given price, or – as will be discussed in some detail below – the opportunity to strike a bargain with someone who has something the searcher wants. The value of opportunities is denominated in the same units as the cost of search, k. These units can be in monetary or utility terms; since most search theory assumes constant marginal utility, however, there is little practical difference between the two approaches.[2]

After each draw the searcher has a choice: he can keep what he has drawn or he can pay k and draw another opportunity from the distribution $F(\ )$. It is clear from this description that the searcher will reap a profit consisting of the opportunity he eventually accepts minus the search costs he pays. This profit need not be positive; if all opportunities have negative value (as they will when the searcher is seeking to buy something at the lowest possible cost and value is denominated in monetary units) he will suffer a loss. The profit the searcher earns is a random variable whose value depends both on the actual draws he gets from the distribution $F(\ )$ and on his decisions to accept or reject particular opportunities. The strategy he uses will determine the expected value of his profit. An optimal decision rule[3] maximizes the expected value of the profit.

Let V^* be the expected value of the searcher's profit if he follows an optimal strategy. Clearly the searcher should never accept an opportunity with value less than V^*. If he rejects the opportunity he is in the same situation as a searcher who is starting anew: he can expect to make a profit of V^*. The timing is such that search costs are incurred immediately, but any benefits from search are received in the next period; and the searcher discounts future gains using the discount factor δ. Thus V^* must satisfy

$$V^* = \delta \int_{-\infty}^{\infty} \max[y, V^*]\,\mathrm{d}F(y) - k. \tag{1}$$

The searcher follows a *reservation-value* rule: he accepts all offers greater than or equal to V^* and rejects all those less than V^*. The reservation property of the optimal search rule is a consequence of the stationarity of the search problem. We assume that the searcher who discards an opportunity and starts searching again is in exactly the same position as he was before he started searching. If the searcher's situation changes, then he will change his search behavior. The searcher's situation

[1] The job-search literature is surveyed by Mortenson (1986).

[2] Exceptions include Danforth (1979), Hall et al. (1979), and Manning and Morgan (1982).

[3] It can be shown that an optimal rule exists under very mild assumptions [see De Groot (1970), Kohn and Shavell (1974), Lippman and McCall (1976, 1981), McCall (1970)]. If, however, $F(\ )$ has no finite moments, an optimal decision rule does not exist. The reservation-price rule has been extended to the case where the searcher can take more than one observation at a time, choosing his sample size [Benhabib and Bull (1983), Gal et al. (1981), Harrison and Morgan (1990), Morgan (1983, 1986), Morgan and Manning (1985)]; and to the case of search across several goods [Anglin (1990), Burdett and Maleug (1981), Carlson and McAfee (1984), Vishwanath (1988), Weitzman (1979)].

can change either because the distribution $F(\ )$ changes,[4] or because the cost of search changes.[5]

It is instructive to use the fact that the optimal search strategy has the reservation property to calculate V^*. If the searcher sets a reservation value of x, then the value of searching is

$$V(x) = \delta\left[F(x)V(x) + \int_x^\infty y\,\mathrm{d}F(y)\right] - k. \tag{2}$$

This equation states that if the searcher sets a reservation value of x, the expected profits from searching are equal to the discounted value of next period's expected benefits minus the cost of search. With probability $F(x)$ the searcher will reject the opportunity and be back where he started – with an expected value of $V(x)$. With probability $1 - F(x)$ he will have chosen a value from the upper tail of the distribution $F(\ )$. The expected value of this choice is $[\int_x^\infty y\,\mathrm{d}F(y)]/[1 - F(x)]$. From equation (2),

$$V(x) = \frac{\delta \int_x^\infty y\,\mathrm{d}F(y) - k}{1 - \delta F(x)}. \tag{3}$$

Let x^* maximize $V(x)$. Then $V(x^*) = V^*$. It is easy to check (by differentiating Eq. (3) and setting the derivative to zero) that $x^* = V^*$ as claimed and to derive an implicit equation for x^*:

$$x^* = \frac{\delta \int_{x^*}^\infty y\,\mathrm{d}F(y) - k}{1 - \delta F(x^*)}. \tag{4}$$

This equation has a simple interpretation: V^* or x^* represents the expected discounted value of net benefits.[6] It is useful to rewrite Eq. (4) as

$$x^* = \delta\left[x^* + \int_{x^*}^\infty (y - x^*)\mathrm{d}F(y) - k\right]. \tag{5}$$

[4] The distribution $F(\ )$ could change for a number of reasons. Some examples: (i) if search is modeled as being without replacement, so that the searcher discards opportunities as search progresses, the distribution of remaining opportunities changes [Rosenfeld and Shapiro (1981)]; (ii) if the searcher does not know the distribution from which he is drawing, then sampling yields information about it and his subjective estimate of $F(\ )$ changes [Bikhchandani and Sharma (1989), Burdett and Vishwanath (1988), Christensen (1986), Kohn and Shavell (1974), Morgan (1985), Rosenfeld and Shapiro (1981), Rothschild (1974a)]; and (iii) in job-search models, the searcher ages as search progresses, so that lifetime wages decline [Diamond and Rothschild (1989, pp. 450–454), Groneau (1971)].

[5] Having search costs increase is a way of introducing changing marginal utility into the analysis. In the job-search literature it is reasonable to assume that as searchers have been unemployed longer, the cost of search increases. Sometimes the cost of search can be directly affected by government policy – as in the length of time the government chooses to pay unemployment benefits [Burdett (1978)].

[6] Note that, since $\sum_{i=1}^\infty [\sum_{j=0}^i \delta^j F(x)^j][1 - F(x)] = [1 - \delta F(x)]^{-1}$, the expected discounted value of the total cost of searching is $k/[1 - \delta F(x)]$.

This equation also has an attractive interpretation. Suppose the searcher has just drawn an opportunity worth x^*. Then the left-hand side of (5) is what he gets if he stops searching and keeps x^*. The right-hand side is his expected discounted profit if he searches exactly one more time; if on that search he gets something better than x^*, he keeps it; otherwise he stops searching and keeps x^*. Equation (5) states that the expected discounted values of these two strategies are the same. We may summarize the discussion as follows:

Theorem. *If it costs k per unit to pick a draw from a distribution F (with finite first and second moments) then the optimal search rule is a reservation-value rule, where the reservation value x^* satisfies Eq.* (4). *The gain to the searcher from following this optimal strategy is given by Eq.* (3), *with $x = x^*$.*

One important property of the optimal search rule is that it is *myopic* in the following sense: the searcher who follows a reservation price strategy will never decide to accept an opportunity he has once rejected. Thus, in deciding whether or not to accept an opportunity he need only consider whether he wants it now; he need not worry that he might at some later date find it attractive. In technical terms the optimal search strategy is the same whether or not recall is permitted. Myopic search rules are attractive to economic theorists because if agents follow them economic behavior can be simply modeled. A market in which prospective buyers retain the right to take up offers previously made is much more complicated than a market in which all offers are made on a take-it-or-leave-it basis. If search is myopic this complexity need not be modeled; searchers would not avail themselves of the opportunity to take up offers once spurned. The tractability and plausibility of the bargaining models to be described in Section 4 depends on agents' myopic search rules.

The myopic property is distinct from the reservation-value property. A stationary reservation-value rule is myopic. However, it is easy to construct examples where the optimal search rule is myopic but does not have the reservation-value property [see Rothschild (1974a)]. Similarly, if the searcher follows a reservation-value rule but the value is falling (as will be the case if the cost of searching is rising), then the optimal search rule will not be myopic. Stationary optimal search rules are myopic; if a searcher's situation does not change as he searches, his decision rule will not change. Stationarity is not necessary for the myopic property, however: Rosenfeld and Shapiro (1981) give examples of optimal search rules which are myopic but not stationary (because the searcher is learning about the distribution of values as he searches).

Two important comparative statics results can be derived from Eq. (4) or Eq. (5). First, $\mathrm{d}x^*/\mathrm{d}k < 0$ and $\mathrm{d}x^*/\mathrm{d}\delta > 0$: as the cost of search or the cost of time increases the searcher becomes less picky (and the value of the entire search enterprise declines). Second, because a mean-preserving spread of $F(\ )$ will increase $\int_x^\infty y\,\mathrm{d}F(y)$, as the distribution $F(\ )$ becomes more dispersed [in the sense of Rothschild and Stiglitz (1970)], V^* and x^* increase.

Many studies of search adopt a slightly richer formulation of the searcher's problem. Suppose that instead of paying a fixed cost k for an opportunity to draw from the distribution $F(\ )$, the searcher looks for opportunities with an intensity which he controls. Specifically, suppose that opportunities arrive as a Poisson process with an arrival rate of s and that someone who searches with an intensity of s for a length of time T incurs search costs of $k(s)T$. The Poisson assumption (which preserves stationarity in what is now a continuous time setup) means that in a short time interval, Δ, the probability that precisely one opportunity arrives is $s\Delta + o(\Delta)$.

We use the same argument that led to Eq. (2) to analyze this model. Assume that the time interval Δ is so small that we may ignore that $o(\Delta)$ possibility that more than one opportunity arrives in Δ. When the searcher controls both the intensity with which he searches and the reservation value, the probability that a searcher will accept an offer in an interval Δ is approximately $s\Delta[1-F(x)]$, or the probability that he gets an opportunity times the probability that the offer is accepted. Thus, if the searcher follows a policy with values s and x, his expected gain is $V(s,x)$ where $V(s,x)$ satisfies (with r denoting the searcher's discount rate)

$$V(s,x) \approx e^{-r\Delta}\left([1-s\Delta+s\Delta F(x)]V(s,x)+s\Delta\int_x^\infty y\,dF(y)\right)-k(s)\Delta. \tag{6}$$

The interpretation of Eq. (6) is exactly the same as that of Eq. (2). With probability $s\Delta[1-F(x)]$ the searcher will accept an offer with expected value $[\int_x^\infty y\,dF(y)]/[1-F(x)]$; with complementary probability we will reject the offer and start searching again. Whether the searcher accepts an offer or not, he incurs search costs of $k(s)\Delta$ in searching over the interval. Once again, we can solve for $V(s,x)$. Approximating $e^{-r\Delta}$ by $1-r\Delta$, and discarding all terms involving Δ^2, we obtain after simplification

$$V(s,x)=\frac{s\displaystyle\int_x^\infty y\,dF(y)-k(s)}{r+s[1-F(x)]}, \tag{7}$$

which has the same interpretation[7] as Eq. (4). Again, it is easy to see that if x^* is chosen to maximize $V(s,x)$, then $V(s,x^*)=x^*$. If s^* is chosen to maximize $V(s,x^*)$

[7]Note again that the expected discounted costs of searching are

$$\int_0^\infty k(s)\int_0^t e^{-ru}\,du\, s[1-F(x)]\,e^{-s[1-F(x)]t}\,dt=\frac{k(s)}{r+s[1-F(x)]}.$$

then

$$k'(s) = \int_{x^*}^{\infty} (y - x^*)\,\mathrm{d}F(y); \tag{8}$$

search intensity is set so that the marginal cost of increasing search intensity is equal to the expected improvement from an additional draw. It is straightforward to rewrite Eq. (7) in a form similar to Eq. (5):

$$rV(s, x^*) = s \int_{x^*}^{\infty} (y - x^*)\,\mathrm{d}F(y) - k(s). \tag{9}$$

We may summarize this discussion as follows:

Theorem. *If opportunities arrive as a Poisson process with arrival rate s, where k(s) is the cost per unit time of generating search opportunities with intensity s, then a reservation-value rule is optimal, and the optimal intensity, reservation price, and value satisfy Eq.* (7), (8), *and* (9).

3. Price dispersion

The classical law of one price says that frictionless competition will force identical items to be sold at the same price; but in fact homogeneous goods often sell for widely varying prices.[8] Can search costs result in an equilibrium with dispersed prices? As we have seen, in the Diamond (1971) model with identical buyers and sellers, there is no price dispersion in equilibrium; all sellers charge the monopoly price. To generate a price distribution, there must be some heterogeneity among sellers and/or buyers. The sources of price dispersion include differences in the sellers' production costs [Bénabou (1988a), Bester (1988a), Carlson and McAfee (1983), MacMinn (1980), McAfee and McMillan (1988), Reinganum (1979)]; differences in buyers' search costs [Axell (1977), Bénabou (1988a), MacMinn (1980), Rob (1985), Stahl (1989), Stiglitz (1987), von zur Muehlen (1980)]; differences in buyers' beliefs about the price distribution [Rothschild (1974b)] or preferences [Diamond (1987)]; the use by buyers of nonsequential search strategies [Braverman (1980), Burdett and Judd (1983), Chan and Leland (1982), Gale (1988), Hey (1974), Sadanand and Wilde (1982), Salop and Stiglitz (1976), Schwartz and Wilde (1985), Wilde (1977, 1987), Wilde and Schwartz (1979)]; the repetitiveness of purchases and resultant customer loyalties [Bénabou (1988a), Cressy (1983), McMillan and Morgan (1988), Rosenthal (1982), Sutton (1980)]; the use by sellers of mixed strategies, varying their prices over time [Shilony (1977), Varian (1980)]; stockpiling by buyers [Bucovetsky (1983), Salop and Stiglitz (1982)]; and advertising by sellers

[8] Carlson and Pescatrice (1980), Dahlby and West (1986), Pratt et al. (1979), Stigler (1961).

that randomly reaches buyers, inducing differences in buyers' information about prices [Butters (1977)].

Most extant models of price dispersion assume away much of the complexity of the bargaining between buyer and seller by assuming that only the buyers search and that the "bargaining" consists of the seller making a take-it-or-leave-it price offer to any buyer who has found him. Thus the sellers play a Nash noncooperative game among themselves and a Stackelberg game against the buyers, who take the prices they find as given.

One way of having buyers differ in what they know is to posit advertising by sellers that reaches buyers randomly. In the seminal model of Butters (1977), buyers demand one unit up to a maximum price of a. All sellers have the same constant average production cost c. For an advertising cost of b a seller reaches a single buyer, but the seller cannot target a particular buyer; each buyer has an equal chance of receiving a message. Buyers do no search for themselves, but just purchase from the lowest-price seller whose message they have received. The main result is that in equilibrium all prices strictly between $c + b$ and a are advertised. To establish this, suppose there were an interval (p^-, p^+) within $(c + b, a)$ for which no prices were advertised. Then a seller advertising p^- could increase his profit per sale by $p^+ - p^-$ with no loss in sales by raising his price to p^+; this could not be a Nash equilibrium. In particular, if the highest price advertised were less than a then the highest-price seller could increase profit by raising his price to a. Finally, suppose the lowest price were strictly higher than $c + b$. Then the lowest-priced seller could get an extra sale for sure by sending an additional message, and strictly positive profit from this sale. (Since the seller is an infinitesimal part of the market, reaching a buyer he has already reached is a probability-zero event.) This is inconsistent with equilibrium. Hence the advertising induces price dispersion.

Butters's model shows that, for price dispersion to exist when sellers are identical, buyers must differ in what they know at the time they purchase. If buyers can search for themselves across sellers, then after they have finished acquiring information, different buyers must have found different best prices. For competition among sellers not to eliminate price dispersion when sellers have identical production costs, there must be some buyers who know only one price at the time of purchase [as observed by Wilde (1977)]. If all buyers know at least two prices, price differences are not consistent with Nash equilibrium; one of the identical sellers could change his price so as to attract more buyers and increase his profits. On the other hand, there must be some buyers who know two prices for there to be price dispersion; if all buyers could learn only one price the equilibrium would be at the monopoly price. Burdett and Judd (1983) give a model of information acquisition that leaves some buyers knowing only one price, and some knowing two. All sellers have the same constant production cost, and all buyers have the same search cost. Buyers are assumed not to use a sequential sampling rule but instead to use a fixed-sample-size rule: they commit in advance of sampling to a sample size. At any equilibrium, there are always some buyers who sample once, and there may be some who sample twice. To establish this, note that, if all buyers took two or more samples, price would be driven down to marginal cost; but once this happened it would be in no buyer's interest to take more than one sample. Hence equilibrium requires that some buyers search only once. Since all search costs are identical, either all buyers observe the same number of prices or they are indifferent between observing n and $n+1$ for some integer n; but we have established that n must equal one. Hence samples of at most two are taken. If the search cost is high enough, each searcher samples only one seller, and the only equilibrium is at the monopoly price. But it can be shown [see Burdett and Judd (1983) for the algebra] that for low enough search costs there exist equilibria in which some searchers sample two sellers, and therefore prices are dispersed. Related models that work by having some buyers sample only one seller while other buyers sample more than one seller include Braverman (1980), Chan and Leland (1982), Sadanand and Wilde (1982), Salop and Stiglitz (1977), Schwartz and Wilde (1979, 1985), and Wilde and Schwartz (1979).

If the sellers are not identical, then a dispersion of prices might arise simply as a reflection of the dispersion of production costs. To exemplify how the heterogeneity of sellers' production costs can create price dispersion, consider the model of Reinganum (1979). There are many sellers each with constant average cost c drawn from a distribution $G(c)$ with support $[c_0, c_1]$, with $c_0 < c_1 \leqslant (c_0 e)/(1+e)$. There are many identical buyers with the indirect utility function $U(P,p)+W$, where W represents wealth, p the price of the searched-for good, and P the vector of (nonstochastic) prices of all other goods. Let $q(p)$ represent the corresponding demand curve and assume that it has constant elasticity $e < -1$. All buyers know the prevailing distribution of prices $F(p)$ on $[p_0, p_1]$. The search cost is k per sample. As in Section 2, a buyer searches until he finds a price at least as low as his reservation price. The value of searching when the reservation price is p_r is

$$V(p_r) = [1 - F(p_r)]V(p_r) + \int_{p_0}^{p_r} U(P,p)\,\mathrm{d}F(p) - k. \tag{10}$$

This is analogous to Eq. (2).[9] After solving Eq. (10) for $V(p_r)$, differentiating, and putting the result equal to zero, we find that the optimal reservation price p_r^* is defined, analogously to Eq. (4), by

$$\int_{p_0}^{p_r^*} [U(P,p) - U(P,p_r^*)]\,\mathrm{d}F(p) = k. \tag{11}$$

The quantity demanded by any buyer at any price p is $q(p)$ if $p \leqslant p_r^*$ and zero otherwise. An equilibrium consists of a reservation price p_r^* and a price distribution $F^*(p)$ such that (a) given F^*, buyers choose their optimal reservation price p_r^*; and (b) given p_r^*, the sellers collectively generate F^* by each setting the price that

[9] But (16) differs from (2) in that the buyer's utility is not linear in price; lower draws from the distribution are better, whereas in (2) high draws are desired; and the discount factor δ is set equal to one.

maximizes profit. The result to be established is that there exists an equilibrium with price dispersion; that is, $\mathrm{d}F^*(p) > 0$ on $[p_0^*, p_1^*]$, with $p_1^* > p_0^*$. The equilibrium price distribution is constructed as follows. Let $F(p) = G[p(1+e)/e]$ on $[p_0, p_1] = [c_0e/(1+e), c_1e/(1+e)]$. Then there is a unique reservation price p_r^* defined by Eq. (11), which can be shown to satisfy $p_0 < p_r^* \leqslant p_1$. A seller maximizing profits will set his price $p \leqslant p_r^*$ since otherwise profit is zero. Given this, any buyer will buy from the first seller he visits. All sellers look alike to a buyer, so λ, the ratio of buyers to sellers, is the expected number of buyers who draw their first sample from any particular seller. A seller with cost c chooses a price to maximize his expected profit, which is $(p-c)q(p)\lambda$ if $p \leqslant p_r^*$ and is zero if $p > p_r^*$. The price p^* that maximizes profit is given by the marginal-revenue-equals-marginal-cost condition $p^*(1+e)/e = c$, provided $p^* \leqslant p_r^*$; and $p^* = p_r^*$ otherwise. Since $p_r^* > p_0 \geqslant c_1$, all sellers make positive profit, so none exits. The resulting prices range from $p_0^* = c_0e/(1+e)$ to $p_1^* = p_r^* \leqslant c_1e/(1+e)$; and the induced price distribution is $F^*(p) = G[p(1+e)/e]$, but with a mass point at p_r^*. It remains to show that p_r^*, defined to be the reservation price for F, remains the reservation price for F^*. But F and F^* coincide except at p_r^*, where F^* has a mass point. At p_r^* the integrand in Eq. (11) is zero, so the equation defining the reservation price remains the same when F^* replaces F. Hence the price distribution induced by the sellers' cost distribution is consistent with optimal search by buyers.

As in the Diamond (1971) monopoly-price model, in Reinganum's model the buyers' search costs turn each seller into a local monopolist. But because the sellers have different costs and the buyers have downward-sloping demands, the sellers exercise their monopoly power by setting different prices, creating an equilibrium price distribution. Perversely for a model of search, no search actually takes place: each buyer purchases from the first seller he encounters. Bénabou (1988a) shows, however, that generalizing the model by giving buyers a distribution of search costs results in active search by the buyers.

All of the price-dispersion models so far discussed are static. In the model of McMillan and Morgan (1988), buyers purchase the good in each period over an infinite time horizon. A buyer need pay no search cost to return to the seller he patronized in the previous period, but it is costly to learn the price of any other seller. As a result of the repetitiveness of purchases, a seller's customers rationally form implicit contracts with the seller to purchase repeatedly from him; and the seller reciprocates by implicitly contracting not to vary his price over time. If a seller raises his price, he induces his marginal customers (those with a reservation price just above his former price) to search for an alternative seller. But if he lowers his price then, on the Nash assumption that only he has changed his price, he gets no new customers, as all the other buyers remain with their accustomed seller. Thus the price elasticity of a seller's demand is higher for price rises than price cuts; the demand curve facing each seller is kinked. Because the corresponding marginal-revenue curve is discontinuous, many prices are consistent with optimizing behavior; in particular, there can be price-dispersed equilibria.

4. Search and bargaining

The parties to a negotiation are usually able, with effort and some luck, to develop alternative opportunities. Common-sense advice for a bargainer is to work on improving his alternatives, for the better his fallback, the stronger his bargaining position. In this section, we expound a model that corroborates this common-sense view.

Examining the bargaining foundations of search theory, or adding search to bargaining theory, eliminates some unsatisfactory features of both search theory and bargaining theory. Bargaining theory traditionally assumes exchanges are idiosyncratic: a single potential buyer faces a single potential seller. In some applications this is the appropriate assumption (for example, a negotiation between an insurance assessor and a claimant); but in most economic negotiations alternative trading partners can be searched for. Search theory, on the other hand, usually posits an extreme outcome to the bargaining between buyer and seller: after a searching buyer has located a seller, the seller makes a take-it-or-leave-it price offer [as in the Diamond (1971) model and the price-dispersion models discussed above, for example]. Such offers are not subgame perfect; if the buyer rejects the offer it is not in the seller's interest to refuse to bargain. The implicit assumption, therefore, is that the seller has the ability to make commitments. In some applications this is appropriate: a store might refuse to bargain with one customer because bargaining would destroy its ability to make credible take-it-or-leave-it offers to other customers and therefore reduce the profits it extracts from the other customers. But in many applications it is unrealistic to assume that one of the agents can capture most of the gains from trade.[10]

The line of research that assumes that both sellers and buyers incur search costs in finding potential trading partners and investigates the bargaining between any matched buyer and seller was begun by Diamond, Maskin, and Mortenson.[11] Diamond (1981, 1982) and Mortenson (1982a,b) represent the bargaining process

[10] In the model of McAfee and McMillan (1988), it is the searching buyer, rather than the nonsearching seller, who makes commitments. Each potential seller has private information about his own costs, and extracts rents from this information by quoting a price strictly above his cost. The buyer/searcher optimally announces not one but two reservation prices, p^* and p^{**}, with $p^{**} > p^*$. The buyer immediately purchases if he finds a seller asking a price less than the lower reservation price p^*; and he immediately rejects any seller asking a price above the higher reservation price p^{**}. Any seller quoting a price between the two reservation prices is put on a list and asked to wait. If the buyer ends up sampling all of the potential sellers without getting a price quote below p^*, he returns to, and purchases from, the cheapest of the listed sellers. If the buyer receives no quotes below p^{**}, he makes no purchase. Related analyses include Bester (1988a, b), Daughety and Reinganum (1991), Fudenberg et al. (1987), and Riley and Zeckhauser (1983).

[11] Diamond (1981, 1982, 1984a, b), Diamond and Maskin (1979, 1981), Mortenson (1976, 1982a, b; 1988). Other contributors to this line of research include Bester (1988a), Binmore and Herrero (1988a, b), Deere (1988), Gale (1986, 1987), Howitt (1985), Howitt and McAfee (1987, 1988), Iwai (1988a, b), McLennan and Sonnenschein (1991), McKenna (1988), Peters (1991), Pissarides (1985), Rosenthal and Landau (1981), and Rubinstein and Wolinsky (1985).

by the cooperative Nash bargaining model (see the Chapter in this Handbook by Thomson).[12] The most detailed investigation of the strategic interactions between search and bargaining is that of Wolinsky (1987), based on noncooperative bargaining concepts; we shall follow Wolinsky's analysis here.

If neither bargainer had an alternative trading partner, sequential bargaining would divide equally the surplus being bargained over, provided buyer and seller were equally patient and the time between offers was short (see Chapter 7 of this Handbook by Binmore, Osborne, and Rubinstein). The existence of alternatives, however, means that the negotiated division of the surplus depends upon the bargainers' search capabilities. The buyer's ability to find an alternative seller increases the share of the surplus he can negotiate; and the seller's ability to find an attractive alternative reduces the buyer's negotiated share. To make this idea precise, consider a market in which many potential buyers and sellers search for each other. When a pair meets, they learn that the difference between the seller's and the buyer's valuation is m. Ex ante, m is viewed as a random draw from a continuously differentiable distribution F with support $[0, m^+]$. Let the subscript 1 denote sellers and 2 buyers. After meeting, a pair can either negotiate a price and leave the market, or continue to search. As in the second model in Section 2 above, search takes place in continuous time; a searcher chooses his search intensity s_i, $i = 1, 2$, where s_i is the probability that, within a unit interval of time, the searcher initiates a contact with an agent of the opposite type. Search activity costs the searcher $k_i(s_i)$ per unit of time, where $k_i(s_i)$ is an increasing, concave function. Let s_i^0 represent the probability per unit of time that the type i agent is contacted as a result of the search activity on the other side of the market: if there are N_i searchers of type i, $i = 1, 2$, then $s_i^0 = (N_j/N_i)s_j$, $j \neq i$. Thus, given that there are many buyers and sellers, the probability that a type i agent is matched is $(s_i + s_i^0)$ per unit of time. There is a common rate of time preference r. Assume a steady state: the (exogenous) rate of entry of new searchers equals the (endogenous) rate of exit as agreements are made. Equilibrium in this game is characterized by an agreement $(w_1(m), w_2(m))$ that divides the surplus from the match, m. If one, and only one, of the players could make commitments (as the seller was assumed to be able to do in the price-dispersion models of the previous section), he would get the whole surplus, m. Let us require instead that both bargainers behave in a subgame-perfect way. The derivation of the perfect equilibrium combines the techniques of optimal search decisions, given in Section 2 above, with the backward-induction method of finding perfect equilibrium in a bargaining model (exposited in the Chapter by Binmore, Osborne, and Rubinstein). We shall give an outline; for the details, see Wolinsky (1987).

First, consider search strategies. An agent of type i chooses a search intensity s_i and a constant reservation value m (i.e., he takes the first opportunity whose

[12] Diamond and Maskin (1979) and Diamond (1984a) assume the bargaining results in equal division of the surplus, which would be the Nash solution if the bargainers had identical disagreement payoffs.

joint surplus exceeds m).[13] Let $V_i(s_i, m; s_i^0)$ represent the present discounted value of this search policy. Then V_i satisfies a modified version of Eq. (9):

$$rV_i(s_i, m; s_i^0) = (s_i + s_i^0) \int_m^{m^+} [w_i(y) - V_i(s_i, m; s_i^0)]\,\mathrm{d}F(y) - k_i(s_i). \tag{12}$$

A searcher can be in one of two different situations: either he is unmatched, or he has already found a partner and is in the process of negotiating. Consider the former. Define

$$V_i^* \equiv V_i(s_i^*, m^*; s_i^0) = \max_{s_i, m} V_i(s_i, m; s_i^0). \tag{13}$$

Here s_i^* and m^* characterize optimal search by an agent who has not yet found a match, given s_i^0, $w_i(m)$, and $F(\ )$. A match will be made only if $m \geqslant V_1^* + V_2^*$; otherwise the two agents are better off continuing to search for partners. A searcher who is already matched, on the other hand, has a simpler decision than one who is still looking for a partner. His reservation value is fixed at the surplus he has already found, m (which must exceed m^* or he would have rejected it). His only choice is the rate of search, s_i^{**}, which he sets to equate the marginal benefit in terms of expected improved match to the marginal cost, as in Eq. (8):

$$\int_m^{m^+} [w_i(x) - w_i(m)]\,\mathrm{d}F(x) = k_i'(s_i). \tag{14}$$

Since $m > m^*$, this implies slower search: $s_i^{**} < s_i^*$. The corresponding expected return is $V_i^{**} = V_i(s_i^{**}, m, s_i^0)$.

The main result from this analysis shows how the two search decisions shape the bargaining agreement. Recall that tne limiting perfect equilibrium in a sequential bargaining model is the same as the Nash cooperative solution, provided the disagreement point for the Nash solution is appropriately chosen (see Chapter 7 of this Handbook by Binmore, Osborne, and Rubinstein). That is, the spoils are divided so as to maximize the product of the two bargainers' net gains from the agreement. The division of the surplus at a perfect equilibrium of this search-and-bargaining game, when the time between offers goes to zero, is given by

$$w_i(m) = (\tfrac{1}{2}[m + d_i(m) - d_j(m)], \quad i \neq j = 1, 2, \tag{15}$$

where $d_i(m)$, $i = 1, 2$, is a weighted average of the returns from the two kinds of search:

$$d_i(m) = \alpha_i V_i^{**} + (1 - \alpha_i) V_i^*, \tag{16}$$

where, in turn, the weights reflect the search rates, the discount rate, and the

[13] The assumption of a large number of searchers of either type means that we need not consider the interactions among the search decisions of different agents of a given type. On such interactions when the number of searchers is small, see Reinganum (1982, 1983).

probability of finding a better match:

$$\alpha_i = \frac{r + (s_i + s_i^0)[1 - F(m)]}{r + (s_i + s_i^0 + s_j + s_j^0)[1 - F(m)]}, \quad i \neq j = 1, 2. \tag{17}$$

Equation (15) defines the Nash cooperative solution for dividing the sum m with the disagreement point (d_1, d_2) [since (15) maximizes the Nash product $(w_1 - d_1)\cdot(w_2 - d_2)$ subject to full division of the surplus, $w_1 + w_2 = m$]. Equation (16) defines this disagreement point to be the weighted average of V_i^* (i.e., the return agent i expects if the negotiations break down because agent j finds a better match, so that agent i must search for another partner) and V_i^{**} (i.e., the return agent i expects if he searches while negotiating with his current partner). To summarize:

Theorem. *Consider a market in which many potential buyers and sellers search for trading partners. The difference between a buyer's and a seller's valuation is m, which is a random draw from a continuously differentiable distribution F. The searchers have a common rate of time preference r. Both buyer and seller can choose their search intensities. Let s_i, $i = 1, 2$, represent the probability (chosen by the searcher of type i) that within a unit interval of time the searcher finds an agent of the opposite type; and let s_i^0 represent the probability that within a unit interval of time an agent of type i is contacted as a result of search activity on the other side of the market. V_i^* is the return to search by a searcher who has not yet found a match; V_i^{**} is the return to further search by a searcher who has already found a potential trading partner (both are defined above). The perfect equilibrium (as the time between offers approaches zero) of the search-and-bargaining game is defined by Eq.* (15), (16), *and* (17).

Thus an agent's bargaining power is affected by search in two ways.[14] First, the ability to search while negotiating effectively reduces the cost to the agent of delaying agreement. The agent who has the lower cost of delay tends to get the better of the bargain, because of his negotiating partner's impatience to settle. Second, the cost of search for a new partner determines the losses from breakdown. The agent who would suffer less should the negotiations break down is in the better bargaining position. Hence the bargaining solution depends on both the opportunities available in the event of breakdown, and the opportunities for search during the bargaining. It pays a bargainer to have low search costs.[15]

[14] In equilibrium, agreement is reached immediately a buyer and seller meet (provided m is large enough), because the bargainers foresee these losses from protracted negotiations: there is no time for search during the negotiations. But the implicit, and credible, threat of search shapes the terms of the agreement.

[15] The foregoing analysis assumes that a matched pair know exactly the size of the surplus to be divided between them. For the beginnings of an analysis of the case in which information about the surplus is imperfect, see Bester (1988b), Deere (1988), Rosenthal and Landau (1981), and Wolinsky (1990).

Increasing the search activity of the agents on one side of the market would reduce the expected time without a match of each agent on the other side of the market; in a job-market interpretation of the model, this corresponds to reducing unemployment. Thus, as noted by Deere (1987), Diamond (1981, 1982), Mortenson (1976, 1982a, b), and Wilde (1977), there is an externality: the searchers fail to take into account the benefits their search decisions convey to agents on the other side of the market, and too little search takes place.[16] Diamond (1981, 1982, 1984a, b), Howitt (1985), Howitt and McAfee (1987, 1988), and Pissarides (1985) have used this externality as the driving force in macroeconomic models with some Keynesian properties. Because there is too little job search and recruiting, equilibrium occurs at an inefficiently low level of aggregate activity. If workers search more, the returns to firms' search increase; firms then increase their search, which in turn raises the return to workers' search. This feedback effect generates multiple equilibria; there is a role for macroeconomic policy to push the economy away from Pareto-dominated equilibria.

As the transactional frictions (the cost of search and/or the discounting of future returns) go to zero, does the equilibrium of the search-and-bargaining game converge on the Walrasian equilibrium? In other words, can perfectly competitive, price-taking behavior be given a rigorous game-theoretic foundation? Rubinstein and Wolinsky (1985), Gale (1986; 1987), McLennan and Sonnenschein (1991), Bester (1988a), Binmore and Herrero (1988a, b), and Peters (1991) investigate this question and, under varying assumptions, obtain both affirmative and negative answers; the limiting behavior of search-and-bargaining models turn out to be surprisingly subtle. Rubinstein and Wolinsky (1985) simplify the above model by assuming the value of a match, denoted m above, is the same for all pairs of agents; the agents cannot control their rate of search; and an agent always drops an existing partner as soon as he finds a new one. The perfect equilibrium of this model is determined, as above, by each agent's risk of losing his partner while bargaining. In a steady state in which the inflow of new agents equals the outflow of successfully matched agents, the limiting perfect equilibrium (as the discount rate approaches one) divides the surplus in the same ratio as the number of agents of each type in the market at any point in time, $N_1:N_2$; in particular, the side of the market that has the fewer participants does not get all of the surplus. Is this contrary to the Walrasian model? Binmore and Herrero (1988a, b) and Gale (1986, 1987) argue that it is not, on the grounds that, in this dynamic model, supply and demand should be defined in terms not of stocks of agents present in the market but of flows of agents. Since the inflow of agents is, by the steady-state assumption, equal to the outflow the market never actually clears, so any division of the surplus is consistent with Walrasian equilibrium. A model in which the steady-state assumption is dropped, so that the agents who leave the market upon being successfully matched are not

[16] In the terminology of Milgrom and Roberts (1990), this game has the property of *supermodularity*: one agent's increasing the level of his activity increases the other agents' returns to their activity.

replaced by new entrants, has a frictionless limit equilibrium in which the market clears in the Walrasian sense and the short side of the market receives all of the surplus.[17]

5. Conclusion

The preceding sections have traced the development of the main ideas of search theory.[18] We saw in Section 4 that game theory provides an excellent framework for integrating the theory of search with the theory of bargaining. For the case in which two parties meet and find that a mutually beneficial exchange is possible, but that they can continue searching for other trading partners if a deal is not consummated, Wolinsky (1987) has shown that search theory can be married to bargaining theory in a virtually seamless way. The two theories fit together as well and as easily as hypothesis testing and Bayesian decision theory. One of the more fruitful offspring of this marriage is a satisfactory answer to a question which most other models of search behavior leaves open. In the conventional model of a buyer searching for a purchase, the distribution of offers from which the buyer selects is a given. Clearly, it is worth something to a seller to have potential buyers include that seller's price offer in the distribution from which a buyer is sampling. Since having a place in this distribution is worth something, a natural question is: how is this good allocated; how do sellers become part of the sample from which a buyer selects? In the conventional search literature, the advertising model of Butters (1977) attempts to answer that question. Bargaining theory provides an easy answer. When both sides of the market are modeled symmetrically, then it is clear that what matters to a market participant is making an encounter with someone on the other side of the market. This is determined by the intensity with which a market participant searches (and by the search intensity of those on the other side of the market.) While this merger of the two theories is very neat, it does leave open some questions. Bargaining theory can tell us how, if two parties haggle, a deal is struck, and what the terms of the agreement will be. It does not have much to say, for a given market, about whether haggling is the rule of the day or whether sales are made at posted (and inflexible) prices. An open and fertile area for future research would seem to be the use of search theory and bargaining theory to put a sharper focus on the conventional microeconomic explanations of why different markets operate under different rules.

Search theory provides a toolkit for analyzing information acquisition. Much of modern game theory and economic theory is concerned with the effects of

[17] For more on the literature on the bargaining foundations of perfect competition, see Osborne and Rubinstein (1990) and Wilson (1987), as well as the Chapter by Binmore, Osborne, and Rubinstein.

[18] Other surveys of search theory, emphasizing different aspects of the theory, include Burdett (1989), Hey (1979, Chs. 11, 14), Lippman and McCall (1976, 1981), McKenna (1987a, b), Mortensen (1986), Rothschild (1973), and Stiglitz (1988).

informational asymmetries (see, for example, the Chapters in this Handbook by Geanakoplos (Ch. 40), Wilson (Chs. 8 and 10, Volume I), and Kreps ad Sobel (Ch. 25). Usually in such models the distribution of information – who knows what – is taken as given. In some applications this is natural: for example, individuals' tastes are inherently unobservable. In other applications, however, it might be feasible for an individual to reduce his informational disadvantage: for example, if the private information is about production costs, then it is reasonable to suppose that the initially uninformed individual could, at some cost, reduce or even eliminate the informational asymmetry. The techniques of search theory might be used in future research to endogenize the information structure in asymmetric-information models.[19]

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[19] One such issue – bidders at an auction strategically acquiring information about the item's value before bidding – has been modeled by hausch and Li (1990), Lee (1984, 1985), Matthews (1984), and Milgrom (1981).

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