SEARCH AND THE DEVELOPMENT OF THE ECONOMICS OF INFORMATION

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ABSTRACT

In this paper we trace the evolution of economic search theory and the concomitant accumulation of insights so as to elucidate its successes as well as its central location within the economics of information. The reason for the phenomenal success of search theory is twofold. First, Stigler's fixed sample search was the first entrant in the literature to explicitly model the acquisition of information; furthermore, it was elegant in its simplicity. Second, it was efficacious: it easily accommodated the application of standard methods to endogenously determine the amount of information acquired, thereby extending the Marshallian framework to allow for and explain such phenomena as idle resources and "violations" of the law of one price. After taking up Stigler's pioneering 1961 paper, we continue by considering pre Stiglerian contributions to information acquisition and then McCall's sequential search model and the mathematical developments leading up to it. Following a discussion of further developments in job search and extensions of search to new contexts, we conclude by arguing that search is a concept of enormous breadth.

SÍNTESIS

En este trabajo seguimos la evolución de la teoría de búsqueda económica y la acumulación concomitante de percepciones para dilucidar sus éxitos, así como también su ubicación central dentro de la economía de la información. La razón del éxito fenomenal de la teoría de la búsqueda es doble. En primer término, la búsqueda con una muestra fija de Stigler fue el primer documento en la literatura que en forma explícita modeló la adquisición de información; aún más, fue elegante en su simplicidad. En segundo término, fue eficaz pues con facilidad adecuaba la aplicación de métodos tradicionales para determinar endógenamente la cantidad de información adquirida, entendiendo de esta manera el marco de referencia Marshalliano para dar cabida a y explicar fenómenos tales como los recursos ociosos y las "transgresiones" a la ley de un precio. Después de analizar el trabajo primero de Stigler en su documento de 1961, procedemos a considerar aportes pre Stiglerianos a la adquisición de información y acto seguido abordamos los desarrollos de McCall en su modelo de búsqueda secuencial en la búsqueda de empleo y las derivaciones de la búsqueda a nuevos contextos, para finalmente argumentar que la búsqueda es un concepto de enorme alcance.

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1. INTRODUCTION

The purpose of this paper is to trace the history and evolution of economic search theory and the concomitant accumulation and integration of its insights. Our reasons for setting forth the major steps in the development of search theory include setting right its history and illuminating the connections between search and modern economics. In addition, we promulgate two views. First, search theory was the first (and perhaps the greatest) of many successes in the economics of information; as such, search is central to economics today. Second, search is a concept of enormous breadth: search theory encompasses activities which are quite distinct from the gathering of price information as originally envisioned by Stigler. In our attempt to place George Stigler's pioneering article "The Economics of Information" (1961) in historical perspective relative to earlier research in economics and the advances in statistical decision theory and optimal stopping, we are compelled to locate it center stage.[1] This location is due not to his technical prowess but rather to foresight in being the first to *analyze* information in economics.[2]

In his Nobel laureate address Stigler (1983, p. 533) opines, "The central task of an empirical science such as economics is to provide general understanding of events in the real world" and continues with the caveat that "ultimately all of its theories and techniques must be instrumental to that task." A key point of his

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[1] Stigler was accurate in asserting (1985, p.539), "All I had done was to open a door to a room that contained many fascinating and important problems."

[2] Vickery's "Counterspeculation, Auctions and Competitive Sealed Tenders," the second monumental development in the economics of information, also appeared in 1961. Vickery's paper provides an alternative model of price formation which focuses on the impact of private information possessed by bidders at an auction. While Vickery's contribution to the development of the economics of auctions cannot be overestimated (though we don't believe his contribution to the economics of information is as important as Stigler's), it has had little impact upon search theory. [Points of contact between the vast search and auction literatures recently have begun to emerge. See for example the papers by McAfee and McMillan (1988) and Arnold and Lippman (1991).] Because the focus of this article is the development of economic search, we attend to the line leading to and emanating from Stigler's work and do not return to the vast line which emerged from Vickery's work.

address is the importance of the accumulation of economic knowledge, with the inevitable dispute and rebuttal of ideas. One long accepted idea in the chain of the history of economics is the decisive influence and impact upon market behavior of the economic actors' information. Both this impact and the actors' behavior would, of course, vary with the extent and accuracy of the information possessed by the economic actors. Whereas economists have been aware of the pervasiveness and importance of information for eons and renowned economists such as Knight, Hicks, Schumpeter, Simon, and Alchian understood and wrote about the force of incomplete information in economic life, it has only been since the appearance of Stigler's and Vickery's 1961 articles that the economics of information has evolved in any significant fashion. This point is confirmed in Hirshleifer's 1973 paper, "Where Are We in the Theory of Information": Hayek's 1945 article is the only one of the 30 references in the economic literature dated earlier than 1961.

Because search is one of the mechanisms for acquiring price information and because price formation is the central issue of economic inquiry, Stigler implores us to incorporate search into our models and "systematically take account of the cold winds of ignorance." (1961, p. 225) Referring to the "amounts and kinds of information needed for the efficient allocation of labor" (1962, p. 104) as well as other informational problems such as "the amounts of skill men should acquire," he laments, "The traditional literature has not done these problems justice ... the analysis of the precise problems of information and methods an economy uses to deal with them appears to be a highly rewarding area for future research." (1962, p. 104) Since then not only has the economics of information been removed from Stigler's "slum dwelling in the town of economics" (1961, p. 213), it has become one of the most important and active fields in economics.

Marginal utility was the centerpiece of mid 20th century economics, an engine of analysis that was virtually silent about some of the most important manifestations of economic behavior, including the design, formation, and adaptation of institutions; the persistence of profits in the presence of mobile resources; the existence and persistence of price variability; and the prominence of unemployed resources. Whereas many economic institutions – particularly hedging, insurance, and a host of other pooling mechanisms including share cropping and corporate share holding – owe their existence and structure to the presence of uncertainty, this clockwork centerpiece ignored the impact of chance on behavior. The gathering, processing, and transmission of information are the distinguishing characteristics of advertising, queueing and inventory accumulation, reputation, matching, goodwill, and middlemen. Waiting and shopping also can be productive activities in an uncertain environment. Shopping enables the buyer to accumulate information until an item with the desired qualities and price is selected; similarly, sellers wait until a desirable buyer is found. These dynamic phenomena revealed a flaw in the Marshallian apparatus long recognized by institutional, theoretical, and applied economists.

Prior to Stigler's seminal 1961 article, the role of information had not been analyzed; moreover, "the amount of information possessed by individuals in any market was arbitrarily postulated rather than derived from economic principles." (1983, p. 539) With his simple fixed sample model of search, however, standard economic theory was easily applied to endogenously determine precisely how much information people would acquire. Thus, the profession's ready acceptance of Stigler's contribution is explained by the long perceived need for such a theory, the theory's use of extant tools, and the fact that the theory extended rather than challenged the existing Marshallian framework. Similarly, McCall's recasting of Stigler's framework in 1970 was instantly accepted by the profession for the same reasons. In particular, McCall's important extension was facilitated by the recent development of optimal stopping in the statistical literature. McCall simply joined the two in what appears to be, as it were, a marriage made in heaven. [3]

This paper proceeds with a presentation of Stigler's model and his contribution in section 2 followed by a discussion of early contributions to the economics of job search in section 3. The fourth section begins with a brief tracing of the mathematical developments (including Cayley's problem, the secretary problem, and the house-hunting problem) leading to the sequential search model; it concludes with McCall's sequential job search model. The final section considers the developments in search which flowed from the sequential model. The first subsection treats further developments in job search, especially equilibrium considerations. The following subsections consider extensions of the search model itself, the centrality of search today, new contexts in which it has been successfully applied, and finally a view of search as a broad paradigm.

2. STIGLER'S MODEL AND CONTRIBUTION

To begin, we can't overemphasize our agreement with Lucas (1987, p. 56) when he states that a "model's explicitness invites hard questioning." Like those that preceded him, Stigler saw that the theory of price, the coordinating mechanism of economic allocation, was seriously handicapped by the absence of a formal (i.e., an explicit) theory of information accumulation. Stigler's genius was not in asserting that information should be incorporated into a model in which analysis could be effected but rather in *providing* such a model. His contribution consists in explicitly modeling the information acquisition activity -- and doing so in a manner which satisfied the practical, theoretical, institutional, and empirical demands for a dynamic economic system while maintaining and strengthening the bond with the Marshallian tradition. In particular, his search

[3] We remark in passing that it seems to us that the knot binding search to the stopping rule method seems to be drawn overly tight, hardly permitting new versions of information acquisition to evolve.

model enables the analyst to apply the conventional first order condition: continue gathering information until the marginal value equals the marginal cost. Stigler converted advertising, price variability, and unemployed resources into the basic elements of a Marshallian search model.

Just like Hayek (1945, p. 522), who stressed that it is a gross mistake to suppose that all knowledge of "the particular circumstances of time and place ... should as a matter of course be readily at the command of everybody ...",[4] Stigler starts from the fact (p. 213) that "no one will know all the prices which various sellers ... quote at any given time." From this it followed that search entailed a buyer who, wishing to "ascertain the most favorable price, must canvass various sellers ..." (p. 213)[5]. Taking price dispersion as a manifestation of ignorance in the market (p. 214)[6], Stigler posited this canvassing as the buyer's gathering of n independent offers – say X_1, ..., X_n – from some cumulative distribution function F. With the view that the buyer's chief cost is time, the buyer's cost of search is proportional to the number of offers solicited. (p. 216). Thus, in a few short paragraphs Stigler casts his principles of search in mathematical terms:

select the sample size n so as to minimize $Emin\{X_1, \ldots, X_n\} + nc$.

A number of important results flow from this one-equation model. First, Stigler observes (p. 215) that "increased search yields diminishing (marginal) returns ...", and he also obtains the familiar first order condition (p. 216): "If the cost of search is equated to its expected marginal return, the optimum amount of search will be found."

Second, because the uncertain outcomes associated with search entail transactions at different prices, quite literally, by the luck of the draw/sample, Stigler's new search theory explained violations of the law of one price without taking recourse, as did Jevons, to explanations involving differences in preferences.

Third, to the extent that the act of gathering information is not timeless, search is dynamic. Consider a model with discounting -- namely, minimize $\beta^n Emin\{X_1, \ldots, X_n\} - c(1 - \beta^n)/(1 - \beta)$. Due to the delay associated with additional search,

[4] Because the price system functions so well even in the absence of the centralization of such information, Hayek acclaims it (p. 527) a "marvel."

[5] In his concluding section Stigler (1961) extends this definition of search to include problems "in the detection of profitable fields for investment, and in the workers' choice of industry, location, and job." (p. 224)

[6] Tommasi (1993) argues that consumer ignorance and price dispersion are not unequivocally related in the context of *equilibrium* search models. He provides an example in which consumer search (and hence information) and average prices, but not the variance of the price distribution, depend on a parameter of the model (the number of units purchased.)

the total quantity of search is reduced as the discount factor β falls (so as not to too greatly diminish its usefulness).

Fourth, when the agent doing the search is a job seeker or an individual seeking to sell an asset, we obtain a full blown explanation of idle resources: the activity of unemployment (i.e., search) is an investment incurred to improve the future.[7] As regards price formation, the search explanation of idle resources enables two Marshallian work horses of economic action, waitings and efforts, to be harnessed in tandem.

Stigler proceeded to speak of advertising as the obvious modern method of identifying buyers and sellers (p. 216). Noting that the cost of collecting information is nearly independent of its use, the need for "firms which specialize in collecting and selling information" was clear (p. 220). He also briefly discussed reputation. Finally, with some considerable foresight and concern for the inefficiency generated by price dispersion, he comments (p. 223-24) that manufacturers seek the reduction of uncertainty by setting uniform prices (retail price maintenance) for nationally advertised brands for "if they have eliminated price variation, they have reduced the cost of the commodity (including search) to the buyer."

Prompted by the success of Stigler's new model, the impact upon econometric methods was mammoth though substantially delayed. Whereas uncertainty had previously been modeled as the error term, the new econometrics inserted uncertainty into the structure of the model. The power of this new theory was most apparent in labor economics where an explanation and understanding of unemployment remained elusive. Using the sequential version of the search model, the new econometrics, as exemplified by Heckman and Singer (1984, 1985), Kiefer and Neumann (1989), and Lancaster (1990) succeeded in studying the behavioral effects of unemployment insurance, training programs, and welfare transfers in the labor market.

3. EARLY ECONOMIC CONTRIBUTIONS TO THE ECONOMICS OF JOB SEARCH

As discussed below, many famed economists attempted to link information gathering with labor markets.[8] Though Stigler's 1962 paper "Information in the Labor Market" offered very little in the way of new insights, it did succeed in forging this link by offering up job search as an application of search theory. The large payoffs from providing this link flow from McCall's 1970 follow-on paper.

[7] The notion that by rejecting a low offer the worker is electing voluntary unemployment is due to Lucas. The term "voluntary unemployment" may have originated with Lucas (1976) in his critique of the Phillips curve.

[8] Our tracing of this history is taken from the papers by Feinberg (1978) and Lippman and McCall (1984).

The notion of job search as an explanation for unemployment is present either explicitly or implicitly in the writings of several economists before Stigler's 1962 article. While suggestive for policy, their verbal models contained no mathematical formulation and were neither vulnerable to empirical testing nor sufficiently well developed to comport with analytical work.

Cannan acknowledges the existence of a moral hazard problem associated with unemployment insurance in 1930 when he denies "that unemployment insurance leads to the refusal of available work" and asserts that "the insurance scheme has reduced the economic pressure which used to make persons grab at every chance of employment ... made them, like the old British army, 'ready to go anywhere and do anything.'" In fact, his statement that the job seeker's strategy is not to go on the dole for the remainder of his life but rather to "Take what you can get now, or hold out another week, when something better may turn up." (pp. 46-47) appears, with the advantage of hindsight, like a description of the reservation wage policy.

Writing about wages in 1932, Hicks (p. 45) recognizes the unanticipated unemployment effects of the search which necessarily emanates from the presence of imperfect information when he asserts that firms' "knowledge of opportunities is imperfect [whence] it is not surprising that an interval of time elapses between dismissal and reengagement, during which the workman is unemployed." His statement (p. 45) that "the unemployment of the man who gives up his job in order to look for a better ... may believe that he could get higher wages elsewhere... " implicitly recognizes that voluntary unemployment conjoined with search can be a productive activity. The earliest explicit statement of search unemployment as a productive activity was made by Hutt in 1939:

> A worker ... may refuse immediately available work ... because he feels that to accept it will prevent him from seeking for better openings ... When *actively* searching for work, ... he is really investing in himself ... He is doing what he would pay an efficient employment agency to do ... the search for a better opening is worth the risk of immediately foregone income. (1977, p. 83)

In addition to the labor literature anticipating the job search model, other prominent precursors in the economics of search include Knight, Schumpeter, and Alchian who were concerned with the search for natural resources and the search for inventions.

Knight (1921) was keenly aware of the significance of the ancient activity of prospecting for natural resources. We find his statement (p. 338), "where the possibility of securing wealth by the discovery of natural resources is known ... resources will be attracted into the field of searching for them in accordance with

men's estimates of the chances of success in relation to the outlays to be incurred." closer to a Marshallian than a Stiglerian search-theoretic view.

While the R&D literature had not yet begun, its beginnings are recognizable in the writings of both Knight and Schumpeter. One of the premises of this literature is that innovations resulting in lower costs of production and/or improved product quality must be sought in much the same way that a consumer searches for a low price. Again, Knight's stance (p. 341), "In the case of new knowledge ... it is clear that *in so far* as the results can be predicted the investment of resources in the acquisition of new knowledge will be so adjusted as to ... equate realized values to costs and eliminate profits." is Marshallian.

Schumpeter (1942) continued the advance toward Stigler's introduction of search in his concern for uncertainty and the opportunistic contractual behavior which uncertainty fosters. He not only recognized the need for "safeguarding activities" such as patent protection but also anticipated the tendency to over search when property rights are assigned imperfectly.

> Practically any investment entails, as a necessary complement of entrepreneurial action, certain safeguarding activities such as insuring or hedging. Long-range investing under rapidly changing conditions ... is like shooting at a target that is not only indistinct but moving – and moving jerkily at that. Hence it becomes necessary to resort to such protecting devices as patents or temporary secrecy of processes or, in some cases, long-period contracts secured in advance. (p. 88)

In Alchian's (1951) early evolutionary view, refined and extended by Nelson and Winter (1985), innovations may result from bungled imitation as well as from conscious efforts to improve. His statement (1951, p. 215), "individual motivated behavior based on the pervasiveness of uncertainty and incomplete information. Adaptive, imitative, and trial-and-error behavior in the pursuit of positive profits ...", reveals his view that innovation, like prospecting for natural resources, is a form of search.[9]

4. OPTIMAL STOPPING, DYNAMIC PROGRAMMING, AND THE SEQUENTIAL JOB SEARCH MODEL

Fully nine years after Stigler "opened the door," the economics of information was combined in McCall's 1970 paper, "Economics of Information and Job Search," with emerging mathematical developments including Wald's sequential

[9] See Simon (1951, 1991) for a stochastic theory of the employment relation resembling Wald's sequential rule and a more recent discussion.

analysis (1947), Bellman's dynamic programming (1957)[10], and Markov decision processes.[11] Whereas statisticians had already produced and analyzed systems considerably more advanced than Stigler's simple model, the orientation and presentation was such that their work had little impact in economics until McCall's 1970 article in which their insights were incorporated into what appears to be the "perfect" economic model.

4.1. Mathematical Developments

In the urgent wartime environment[12], Abraham Wald[13] improved upon the double sampling inspection method of Dodge and Romig (1929) and developed the theory of sequential analysis.[14]

While Wald's work was being further developed by statisticians, probabilists were working on the theory of martingales and stopping times.[15] With probabilists located in statistics departments at that time, the timing was ripe for interaction and the development of optimal stopping. During the period of this development, MacQueen and Miller (1960) formulated and solved the house-selling problem. As shown in Example 3 below, it is precisely the sequential search problem McCall presented in 1970. Cayley's problem and the secretary problem –Examples 1 and 2 below– are its two prominent precursors. See Ferguson (1989) for an insightful history and delineation of the development of all of these problems.

[10] Shortly after 1970, dynamic programming became *the* basic analytical tool used in the sequential search literature.

[11] See Howard (1960), Blackwell (1965), Veinott (1966), Denardo (1967), Ross (1983), and Heymand and Sobel (1984).

[12] The Statistical Research Group (SRG) at Columbia University was organized in July 1942 to advise and assist the US military on various statistical problems that arose in the conduct of their wartime activities. The group members included A.H. Bowker, Milton Friedman, M.A. Girshick, Harold Hotelling, L.J. Savage, G.J. Stigler, A. Wald, W.A. Wallis and J. Wolfowitz. Other World War II research groups in Britain and the U.S. contributing to the technical foundations of sequential analysis and optimal stopping include the Enigma Project, the Anti-Submarine Warfare Operations Research Group (ASWORG) and the Quality Control Group in the Ministry of Supply (QCMS).

[13] In his book *Sequential Analysis* (1947), Wald credits Milton Friedman and W.A. Wallis with proposing the problem of sequential analysis. During the war, the cryptographic research conducted in England, headed by Alan Turing, recorded many contributions to statistics and sequential analysis. See Good (1979).

[14] In Dodge and Romig a population is sampled to ascertain whether the proportion of defectives exceeds some specified level. After drawing a sample of size n_1 and counting the number x of defectives, the population is (a) accepted if x is less than a fixed value α, (b) rejected if x exceeds a fixed value $\beta > \alpha$, and (c) a second sample of size n_2 is taken if $\alpha \leq x \leq \beta$ and the accept-reject decision is based on the number of defectives in the sample of size $n_1 + n_2$.
In sequential analysis the decision to accept or reject the null hypothesis is reconsidered after *each* observation: the actual sample size depends on the ongoing history of the sampling process.

[15] If a random variable which tells the decision-maker whether to stop or continue at time t is based only on knowledge of the history of the stochastic process up to time t and not upon the future history of the stochastic process, then the random variable is a stopping time (alternatively stopping rule).

Example 1 (Cayley's Problem): The first stopping problem was proposed by Arthur Cayley in 1875. His problem is a version of the house-hunting problem. Given n objects with known values $v_1 < \cdots < v_n$, the decision-maker seeks to select an object so as to minimize the expected value of the object selected. The objects are presented in a random order, there is no recall of rejected objects and at most $k < n$ objects are presented. In contrast to the usual house-hunting problem, the distribution of the value of the next object to be considered is not independent of the values of the previously viewed objects. ■

Example 2 (The Secretary Problem): The decision-maker is going to select a secretary from amongst n candidates. He interviews them one at a time. The candidates are presented in a random order, and there is no recall of rejected candidates. Each candidate's ability level is observable at the time of interview; however, the actual magnitude of any candidate's ability level supplies no information whatsoever as regards the ability level of remaining candidates. The payoff function for the secretary problem is 1 if the best secretary is selected; otherwise, it is 0. The optimal policy consists in interviewing and rejecting 1/e of the candidates and then selecting the next candidate with the highest rank observed. The probability of selecting the best secretary is 1/e.[16] ■

Example 3 (The House-Selling Problem): Offers $X_1, X_2, \ldots$ arrive one at a time. The offers are independent and identically distributed with known cumulative distribution F. The value of an offer is observable upon arrival, and each observation costs c dollars. The return R_n from stopping after n observations is $R_n = \max(X_1, X_2, \ldots, X_n) - nc$. The problem is to design a stopping rule N to maximize ER_N ■

Shortly after the MacQueen and Miller paper appeared, a host of advances were made.[17] Applications did not lag. In particular, we mention the optimal control of Brownian motion and, especially, the now enormous option pricing literature.[18] Of course, numerous developments in the theory of dynamic programming occurred during the 1970s accompanied by an even larger set of applications in the economics and operations research literatures.[19]

Beginning with the efforts of the Anti-Submarine Warfare Operations Research Group in England during World War II, an enormous literature on detection or search for a hidden object was started, and development continued into the 1960s and 70s (see Stone (1975) for a comprehensive synthesis). Shortly thereafter, the

[16] A very nice sequential formulation of the secretary problem is exposited by Ross (1983).

[17] See Chow and Robbins (1961), Breiman (1964), Dubbins and Savage (1965), Robbins (1970), de Groot (1970), and Chow, Robbins, and Siegmund (1971).

[18] See Bather (1970) and Harrison (1985) for controlling Brownian motions and Merton (1973) for an introduction to option pricing.

[19] Lippman (1975) introduced the case of unbounded rewards. The extension to competitive settings was introduced by Sobel (1971) for stochastic dynamic programming and Mamer (1987) for Chow and Robbins' (1961) monotone stopping problem.

literature on "Multi-Armed Bandit Problems" (MABP), related both to sequential analysis and stopping rules, began to develop. In the bandit problems each observation of the i^{th} arm induces the decision-maker to Bayesianly update his beliefs regarding the payoff associated with arm i. See Berry and Fristedt (1985), Gittens (1979, 1989), and Whittle (1980) for a discussion of MABP and Rothschild (1974) for an application to economic search.

4.2. The Job Search Model in a Sequential Setting

In light of the advances in optimal stopping and the formulation of the house-selling problem, today it seems natural and even obvious that economic job search should be placed in the sequential setting as McCall did in his 1970 article, "Economics of Information and Job Search." He begins (p.115)

> In the simplest job search model the searcher is assumed to know both the distribution of wages for his particular skills and the cost of generating a job offer. Job offers are independent random selections from the distribution of wages. These offers occur periodically and are either accepted or rejected. Under these conditions it is easy to show that the optimal policy for the job searcher is to reject all offers below a single critical number ... Unemployment terminates whenever an offer exceeds the critical value.

Just as in Stigler's original search model (where F is the offer distribution), the sequential model is encapsulated in one equation.[20] The only difference between the two equations is that the fixed sample size n is now replaced by a stopping time N:

$$\textit{select a stopping time } N \textit{ so as to maximize } E\max\{X_1, \ldots, X_N\} - Nc.$$

The optimal stopping time is simply described: accept the first offer which exceeds the reservation wage[21] ξ. The reservation wage ξ solves the first order condition

$$c = \int_{x}^{\infty} (y - x)\, dF(y) \equiv H(x),$$

[20] Mortenson (1970) overlaps with McCall (1970) in its development of a sequential search model. Mortenson also links his novel job search model with the contributions of Friedman and Phelps on the "new" Phillips curve.

[21] We believe Rothschild (1973) was the first to use the term reservation price/wage in the search literature. In the pre-search labor literature, the reservation wage was the intercept of the labor supply curve, the largest wage at which no labor is supplied.

where H(x), the marginal gain from obtaining exactly one more offer, is strictly decreasing (if F has a positive density) and convex. As $H' < 0$, the first order condition has ξ as its unique solution, and it also has a simple interpretation: equate the marginal cost c of taking an additional offer with the expected increase in the return from taking exactly one more search/offer. Thus, the reservation wage is easily computed from this myopic condition. Moreover, it has been shown (for example, see Lippman and McCall (1976)) that ξ is the expected return to search. The time until an acceptable offer is obtained, called the period of *frictional unemployment*,[22] is a geometric random variable with mean $1/(1-F(\xi))$.

With this model and its analytic first order condition for determining the reservation wage, several insights are easily obtained. The *discouraged worker* phenomenon is analyzed for the first time (p. 117). "Consider an individual whose expected returns from remaining unemployed are ϵ_o." He drops out of the labor market if the return ξ to search is less than ϵ_o.

To paraphrase Lucas (1987, p. 67), focusing upon unemployment as an individual rather than an aggregate problem — so that the worker can be viewed as having elected voluntary unemployment — enabled McCall to formulate social policies for dealing with it. The view of unemployment as voluntary has the advantage of inviting an analysis of the forces such as unemployment insurance which impact the choice of unemployment.

Two methods for reducing the number of dropouts are suggested: lowering the cost of search and shifting the offer distribution by adding a constant to each offer. Both changes increase the return to search. Lowering the cost c of search, say by additional government benefits available only while actively seeking employment[23], induces the worker to search. If the wage of each employed worker is augmented by a fixed amount δ either by a direct government subsidy to the employer or by introducing a training program which increases the worker's marginal product, then the effective offer increases by δ and $H_\delta(x) = H(x+\delta)$: the H functions shifts to the right, and the reservation wage increases by δ. In the first case the period of frictional unemployment does indeed increase as claimed on page 119. In the second case, however, it remains constant. In fact, in a model with discounting, adding a constant δ to each job offer causes the period of frictional unemployment to decrease (and the reservation wage to increase by less than δ) precisely because the return to search increases.[24]

[22] Referring to McCall's contribution as "well-known and justly celebrated," Lucas states (1987, p. 54-55) that the "analysis of unemployment as an *activity* was initiated by John McCall." In particular, (1987, p. 66) "it is exactly this 'voluntary' aspect of McCall's formulation that leads it immediately into the first coherent analysis of employment-related risks ..."

[23] In most States unemployment insurance requires active search for employment.

[24] See Theorem 4 of Lippman and McCall (1986).

McCall proceeds with an analysis of a *minimum wage* law on discouraged workers. If a regime with minimum wage m converts each pre regime offer less than m to an offer of 0, then the new H function, label it H_0, decreases in a particular manner: $H_0(x) = H(x)$ for $x > m$, but $H_0(x) = H(m)$ for $x < m$. Each worker whose reservation wage was less than m has a search cost $c > H(m)$; in the minimum wage regime such a worker is forced to drop out of the labor market as $c > H_0(x)$ for all x. [25]

Finally, a model with discounting and jobs which last a finite (random) amount of time is introduced so the searcher must plan to reenter the market to seek future jobs. This model anticipates the soon to emerge work on quits and layoffs.

5. DEVELOPMENTS IN SEARCH

We begin this section by tracing a small portion of the developments in job search followed by pointing out changes, albeit small, in the modelling of the search activity: no longer is search merely a stopping decision. With the aim of showing the central and important role played by search in economic theory today, the third subsection briefly indicates how search has challenged the traditional competitive theory. Our remaining task is to convince the reader that search is indeed a much broader phenomenon than might appear at first blush. To do so we demonstrate in the fourth subsection that there has been a considerable broadening beyond job search in the context and examples studied: the use of a search model renders a good many previously inexplicable problems easily understood. Perhaps more important, the fifth and final subsection discusses our view that information gathering is but one of several aspects of search.

5.1. Developments in Job Search

Due to its mathematical power, conceptual flexibility, and ability to capture the essence of information acquisition, the appearance of the sequential search model in McCall's innovative article spawned a gargantuan job search literature. Much of the early contributions was summarized and extended in the Lippman and McCall (1976) survey article. By that time the basic model had been amended to account for discounting, a random number of offers per period, a finite time

[25] McCall and others did not consider the alternative response of firms to the minimum wage regime: increase the offer distribution by converting all offers less than m to an offer of m. Even though H_m, the new H function, increases for $x < m$, $H_m(x) = H(x)$ for $x \geq m$. Consequently, each worker whose reservation wage was less than m has a search cost c which exceeds H(m) and again will be forced to drop out. In fact, if under the minimum wage regime all wage offers greater than m remain unchanged and all offers less than or equal to m remain less than or equal to m, then each worker whose reservation wage was less than m drops out.

horizon, risk aversion, adaptive search, search in a dynamic (non-stationary) economy, bankruptcy considerations, systematic search, quits and layoffs, on-the-job search, variable intensity of search, occupational choice, and partial recall of past offers. Shortly thereafter considerations of matching and equilibrium came to the fore and several branches of the area metamorphosed into trees.

The basic search model did not allow for or explain quits. We briefly mention two explanations for quits. The first emanates from belated information wherein "certain aspects of the job are revealed to the worker only after the job has been accepted." (Lippman and McCall, 1981, p. 136) This line of work began with Wilde's (1979) formalization of Pencavel's observation (1972) that "the taking on of a job for a trial period may be the optimal method for an individual to discover whether that employment suits him." In Wilde's model search requires 1 period, the number of periods on the job required for revelation of the job-specific characteristic[26] is s, and the utility of a job with wage w and specific characteristic y is u(w,y) where u is nondecreasing in each argument. He shows an increase in s induces (a) an increase in the reservation wage, (b) a decrease in the probability of a quit, and (c) less on-the-job evaluation and more search. Lippman and McCall (1981) obtain similar results in a model in which $u(w,y) = w + y$ where the experience characteristic assumes the values α and $-\alpha$ with probability .5 each. The importance of the experience characteristic increases with α rather than s.

Matching provides the second explanation for quits. The key idea in Jovanovic's (1979) matching model is to interpret the wage w as measuring the *quality* or productivity of the match rather than a wage rate. In Jovanovic's continuous time model both firm and worker gradually learn about the quality of the match.[27] Though similar to the models of belated information, the matching model is more adroit in explicating dynamic phenomena of the labor market. Specifically, the matching process explains the increase in wages with tenure, the declining probability of quits, and the negative correlation between the probability of a subsequent quit and the current wage rate.

The most recent development in the search literature is the marriage between search theory and bargaining theory[28] as exemplified in Wolinsky (1987). Starting with Rubinstein's (1982) strategic bargaining model[29], Wolinsky allows the two parties to simultaneously engage in costly search for alternatives, and the

[26] In the literature a product or job quality which is revealed prior to purchase or working is called a "search" quality whereas it is called an "experience" quality if it is revealed after purchase or acceptance of the job.

[27] A clear exposition of Prescott and Townsend's (1980) discrete time version of Jovanovic's model is given in Sargent (1987, p. 72ff).

[28] Footnote 9 alone of the McMillan and Rothschild (1993) survey lists 23 such papers.

[29] See Shaked and Sutton (1984) for a simple exposition of the Rubinstein model.

bargainers are allowed to vary their search intensity over time. The existence of alternatives to the match shunts bargaining power and a larger share of the surplus to the party with the greater search ability. Wolinsky continues by embedding this bargaining model with search alternatives in a market-matching model. The subtlety of these models is divulged by the fact that Wolinsky obtains results different from those of the closely related models of Diamond (1982), Diamond and Maskin (1979), and Mortenson (1978, 1982).

Because homogeneous goods (or jobs) sold at distinct prices violates the law of one price, Rothschild's (1973) query regarding the existence of an equilibrium supporting price dispersion generated a cottage industry of equilibrium search models which set out to overturn Diamond's (1971) result in which all seller's charge the monopoly price. In Diamond's model sellers are identical as are buyers who all have the same positive search cost. Were the rules of the game turned around so buyers rather than sellers are found making take-it-or-leave-it offers and sellers incur search costs, then the market will clear at the competitive rather than the monopolistic price. One path out of this unsatisfactory result is the search and bargaining models mentioned in the paragraph above. The second path is to introduce some friction or heterogeneity into the model. Sources of heterogeneity to be found amongst the 31 search equilibrium papers mentioned in the McMillan and Rothschild (1993) survey include differences in (a) sellers' production costs, (b) buyers' search costs, (c) buyers' beliefs about F, (d) buyers' nonsequential search strategies, (e) preferences as well as (f) repeat purchases and the ensuing customer loyalties, (g) sellers' time varying prices, (h) buyers' inventory holdings, and (i) (Butters' (1977) model of) advertising which induces differential buyer information.[30]

By now several thousand job search articles have been written, and every graduate economics student has been exposed to search models and become steeped in the economics of information.

5.2. Extensions Beyond Sampling

For Stigler economic search was merely the information-gathering activity which accompanies decision-making. In the simplest setup the economic agent decides to stop gathering information or to continue gathering information: accept the job offer or reject it, continue acquiring information regarding investment opportunities or stop, form a match/merger or look elsewhere. In more recent models, this stopping decision is embedded in a more complex dynamic programming framework. Consider, for instance, the job search problem in which

[30] While this literature is too extensive to list, we call the reader's attention to Burdett and Judd (1983), Butters (1977), Salop and Stiglitz (1977), Lucas and Prescott (1974), Wilde and Schwartz (1979), and the McMillan and Rothschild (1993) survey.

layoffs are anticipated so that the accept/stop decision must be made repeatedly. If layoff (in the presence of discounting) is the only alteration to the simple job search model, then the searcher's reservation wage will be lower than it would have been without the possibility of layoff. Continuing in this vein, consider the model proposed by Fallick (1992) in which there are two market sectors: the sectors are identical except that jobs in the first sector have a lower firing probability. Furthermore, suppose the unemployed worker can elect not only which (or both) sector to search in but also the search intensity in each sector. In addition to the necessity of repeatedly making the accept/stop decision, the searcher must select the sectors in which to search as well as the search intensities within each sector. Fallick's analysis demonstrates that the reservation wage is the same in the two sectors, but search is more intensive in the sector with the lower firing probability.

5.3. The Centrality of Search in Economics

Shortly after the Lippman and McCall survey (1976) appeared, a host of important papers was published in a 1977 symposium issue of the *Review of Economic Studies*. This work challenged the traditional competitive theory by examining the impact of imperfect and costly information in product markets. These extensions of the Stiglerian paradigm, exposited in the work of Butters, Salop, and Stiglitz, demonstrated that the presence of imperfect and costly information gives rise to market power and nullifies the traditional theory of perfect competition. For example, the law of one price fails to hold in Stigler's model in that the luck of the draw determines the buyer's price. In this work, however, it fails in the stronger sense that lack of buyer homogeneity can result in market failure[31] or equilibrium with different customer classes paying different (expected) prices even if there are many buyers and sellers and many of the buyers are well informed. Furthermore, product markets with a small number of firms can be more competitive than markets with a large number of sellers.[32] Finally, the theorist must add imperfect information to his list of imperfections which can lead to price rigidities. These facts substantiate Stiglitz's view that in many instances the traditional competitive theory is fundamentally incorrect and misleading and, more importantly, that informational considerations are in fact fundamental to economic theory.[33]

[31] See Grossman and Stiglitz (1980) for an informational problem which leads to a failure in the capital market.

[32] If there are many firms and one decides to lower its price, little additional search will result. On the other hand, one firm deciding to lower its price will induce a substantial amount of search if there are few firms in the market.

[33] The interplay between information gathering and other standard considerations such as the role of advertising and price discrimination were also treated in the symposium. See Butters (1977) for an elegant model where sellers disperse/search via advertising. Papers which consider the issue of price discrimination include Arnold and Lippman (1992), Katz (1984), Salop (1977), Salop and Stiglitz (1977), and Stiglitz (1989).

While search appears in many contexts and information is a crucial element of today's economic theory, we must not overstate the case: all that is information is not search. Information is transmitted by a great many methods other than search. Search seldom involves the attempt to ferret out the beliefs of other economic agents as is so common in the IO literature and games of incomplete information. For example, commitments and other actions taken by a firm for the purposes of changing the competitor's beliefs or influencing the competitor's action do not fall under the heading of search activities. Thus, the informational problems of bargaining and reputation usually do not lie in the search arena. Similarly, the information conveyed via signalling (level of education attained) or via quantity and other self-selection choices (the amount of insurance purchased and the amount of effort expended in avoiding accidents are critical to equilibrium in settings dealing with moral hazard and adverse selection) is best viewed as something other than search.

5.4. New Economic Contexts

As conceived by Stigler and modified by McCall, search entails the attempt, via (sequential) sampling, of arriving at more accurate beliefs about the state of the world. Originally these beliefs about the state of the world concerned the location of vendors and the prices at which to conduct exchange. Since then sampling to attain accuracy about a plethora of other beliefs has been considered.

Search is the essential ingredient in a class of models we refer to as uncertainty resolution. McCardle (1985) is prototypical of these models: the firm gathers information concerning the profitability of a project/technology so as to decide whether to adopt or reject the project, so the stop gathering information decision is followed by the further decision to accept or reject the project. Similarly, in Li, McKelvey, and Page (1987) the Cournot competitors conduct research (by drawing independent fixed samples) prior to production in order to obtain private information about demand conditions. In both papers search is followed by a further decision: it is adopt/reject for McCardle and selecting a production quantity for Li et. al. In Lippman and McCardle's (1991) "Uncertain Search" paper the uncertainty resolution problem is married to the standard search problem. Presented in the context of technology adoption, it considers drawing from a pool of new technologies (the search aspect) whose values remain unknown even after being drawn (the uncertainty resolution aspect). The searcher either adopts the current technology, purchases an additional observation on the current technology, or rejects the current technology and draws another technology from the pool for observation. Thus, search is embedded in a more complex setting than in McCardle (1985) – the exit value associated with rejecting the project is 0 in McCardle but is endogenously determined (and positive) in uncertain search.

Reinganum (1982) was the first to introduce a competitive search model. In her two period model, Cournot duopolists (timelessly) search for low cost production methods in period one prior to the opening of the market in period two. Using Reinganum's two period setup in which sequential search occurs in the first period and competition occurs in the second period, Mamer and McCardle (1987) place McCardle's (1985) information acquisition model in a competitive setting in which the profits accruing to adoption vary with the number of competitors electing to adopt the new innovation/project.

Search also has been a fundamental feature of a new literature attempting to explain the relationship between price rigidities and inflation (see Bonomo (1993)).

5.5. Search as a Broad Paradigm

For Stigler search entailed buyers canvassing sellers to obtain price information. A second form of search is uncertainty resolution as outlined in the previous subsection; there search entails "information gathering" or sampling to arrive at more accurate beliefs. The search paradigm operates more broadly, even when there is no sampling. Search occurs when information is conveyed by the agent's active and direct elicitation of information. For example, a third form of search entails productive informational activities such as matching, locating trading partners, and ascertaining product quality.

Fourth, and rather distinct from information gathering, search has been effectively employed in modeling directly productive activities. Discovery is the essence of these activities in which "Nature will not autonomously reveal the information; only human action can extract it." (Hirshleifer, 1971, p. 561). The productive efforts necessary to bring about technological change are often modeled *mathematically* as if the effort were search activity. Examples include R&D activities in which resources are expended to locate mineral deposits (prospecting), invent new products and processes, or learn new cost reducing production techniques. Securing a patent is an important method of appropriating the gains flowing from the expenditure associated with search: obtaining a patent is a sign of discovery.

Relatedly, Muth (1986) employs the standard search model to generate a learning curve. Rather than positing cost decay in accord with the standard power function, the search model predicts a power function relationship between cost and cumulative production. In addition, the search theory is consonant with departures from the power function: it successfully explains phenomena such as the plateau effect, sudden cost decreases, and initial concavities. Thus, the very act of engaging in production entails an element of search.

We note in passing that games in which timing plays a role often have a search flavor. Such activities include the vast literature on R&D races.[34] These settings entail "discovery," the fourth type of search activity.

Fifth, search can be used as a conceptual framework. For example, Lippman and Rumelt (1982) employ the search framework to cast their theory of uncertain imitability in which competitive firms encounter the persistence of profits in the presence of mobile resources. The causal ambiguity inherent in the creation of productive processes is modeled *as if* each firm's experienced cost is the result of sampling once from a known cost distribution. In a totally different context, Lippman and McCall (1986) utilize the search framework to provide an operational definition of liquidity; to wit, the liquidity of an asset is measured by the expected time to sale when following an optimal sequential sales policy. Using the comparative statics which are so easily developed in search models, this definition of liquidity is shown to be compatible with a large number of (imprecise) other notions such as Keynes idea (1930, p. 67) that the more liquid asset is "more certainly realisable at short notice without loss."

[34] See Lee and Wilde (1980), Lippman and Mamer (1993), and the survey by Reinganum (1989).

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