Prior Knowledge and the Discovery of Entrepreneurial Opportunities

Scott Shane
R.H. Smith School of Business, University of Maryland, College Park, Maryland 20742
sshane@rhsmith.umd.edu

Technological innovations are usually thought to create business opportunities that are unequivocal and readily apparent to any knowledgeable observer. Drawing on Austrian economics, this article portrays the recognition of such opportunities as distinctive cognitive feats whose accomplishment is conditioned by an entrepreneur's prior experience and education. In-depth case studies demonstrate the multiple opportunities that can arise from a single innovation.

Alan Meyer

Abstract

Before technological change leads to new processes, products, markets, or ways of organizing, entrepreneurs must discover opportunities in which to exploit the new technology. To date, research has not explained adequately why entrepreneurs discover these opportunities, which creates several conceptual problems in the entrepreneurship literature. Drawing on Austrian economics, I argue that opportunity discovery is a function of the distribution of information in society (Hayek 1945). Through in-depth case studies of eight sets of entrepreneurs who exploit a single MIT invention, I show that entrepreneurs discover opportunities related to the information that they already possess. I use these findings to draw several implications that differ from those prevailing in the entrepreneurship literature, including: (1) entrepreneurs do not always select between alternative market opportunities for new technologies; (2) the source of entrepreneurship lies in differences in information about opportunities; (3) the results of prior studies of entrepreneurial exploitation may suffer from bias; and (4) individual differences influence the opportunities that people discover, how their entrepreneurial efforts are organized, and how the government can influence this process.

(*Entrepreneurship*; *Austrian Economics*; *Discovery*)

Introduction

Technological change provides the basis for the creation of new processes, new products, new markets, and new ways of organizing; and entrepreneurship is central to this process (Schumpeter 1934, p. 66). However, before technological change results in this process of entrepreneurial exploitation, entrepreneurs must discover opportunities in which to use the new technologies. Because opportunities do not appear in a prepackaged form (Venkataraman 1997), this process of opportunity identification is far from trivial. In any given new technology, entrepreneurs could fail to identify any opportunities, or could identify the wrong opportunities, making an explanation for the discovery of opportunities an important part of the domain of entrepreneurship research.

Unfortunately, most research on entrepreneurship investigates the entrepreneurial process after opportunities have been discovered (Fiet 1996). Researchers typically adopt this approach because they draw on neoclassical economic or psychological theories that assume people will discover the same opportunities in a given technological change (Khilstrom and Laffont 1979), or discover opportunities that are uncorrelated with the attributes of the discoverers (Evans and Jovanovic 1989). Austrian economics challenges the validity of these assumptions, arguing that different people will discover different opportunities in a given technological change because they possess different prior knowledge (Venkataraman 1997). Because the accuracy of these assumptions has important implications for the development of entrepreneurship theory, I explore them in this article.

Through in-depth case studies of entrepreneurs who exploit a single MIT invention, I show results that challenge

1047-7039/00/1104/0448/$05.00
1526-5455 electronic ISSN

the core assumptions of neoclassical economic and psychological approaches to entrepreneurship. In particular, I show that (1) any given technological change will generate a range of entrepreneurial opportunities that are not obvious to all potential entrepreneurs; (2) entrepreneurs can and will discover these opportunities without searching for them; and (3) any given entrepreneur will discover only those opportunities related to his or her prior knowledge (Venkatarman 1997). This evidence supports the Austrian argument that the discovery of entrepreneurial opportunities depends, in part, on the distribution of information in society (Kirzner 1973) and provides important implications for the theory and practice of entrepreneurship.

This article is organized as follows. In the next section, I review extant perspectives on entrepreneurship and identify important implications of the differences between them. In the third section, I develop specific propositions from Austrian economics about the discovery of entrepreneurial opportunities. In the fourth section, I describe the methodology used to examine these propositions. In the fifth section, I review the empirical support for these propositions. In the final section, I discuss the implications of these results for entrepreneurship research and practice.

Entrepreneurship Theories

Explaining the discovery of entrepreneurial opportunities requires assumptions about the nature of the entrepreneurial process. To date, research on entrepreneurship falls into three schools of thought, each with different assumptions about this process.

Neoclassical Equilibrium Theories

Neoclassical economists (e.g., Khilstrom and Laffont 1979) have proposed equilibrium theories of entrepreneurship. Equilibrium theories assume that markets are composed of maximizing agents whose collective decisions about prices clear markets. In the equilibrium framework, no one can discover a misalignment that would generate an entrepreneurial profit because, at any point in time, all opportunities have been recognized and all transactions perfectly coordinated. Because an equilibrium framework does not allow people to recognize opportunities that others do not see, equilibrium theories explain entrepreneurship by identifying individuals who prefer to become entrepreneurs. For example, Khilstrom and Laffont's (1979) model proposes that people with a greater taste for uncertainty will choose to become entrepreneurs, whereas people with a lesser taste for uncertainty will choose to become employees. In short, equilibrium theories assume that (1) everyone can recognize all entrepreneurial opportunities, and (2) fundamental attributes of people, rather than information about opportunities, determine who becomes an entrepreneur.

Psychological Theories

Psychologists (e.g., Begley and Boyd 1987, McClelland 1961) have proposed theories in which entrepreneurship is a function of stable characteristics possessed by some people and not others. According to this perspective, enduring human attributes—such as need for achievement (McClelland 1961), willingness to bear risk (Brockhaus and Horowitz 1986), self-efficacy (Chen et al. 1998) internal locus of control, and tolerance for ambiguity (Begley and Boyd 1987)—lead some people and not others to choose entrepreneurship. The psychological framework generally focuses on the decision to exploit opportunities rather than on their discovery (Venkataraman 1997). However, when researchers from this perspective explore opportunity discovery, they typically argue that discovery depends on relative differences between people in their willingness and/or ability to search for and identify opportunities (Shane and Venkataraman, 2000). For example, they argue that superior information processing ability, search techniques, or scanning behavior make some people more able or willing to discover opportunities (Shaver and Scott 1991). In short, psychological theories explicitly or implicitly assume that (1) fundamental attributes of people, rather than information about opportunities, determine who becomes an entrepreneur; and (2) this process depends on people's ability and willingness to take action.

Austrian Theories

Austrian economists believe that equilibrium approaches fail to offer a satisfying theoretical framework for understanding market processes. They believe that a viable theory of a market system cannot assume equilibrium but must explain how a market would achieve that equilibrium from nonequilibrium initial conditions (Kirzner 1997). The Austrians assume that markets are composed of people who possess different information (Hayek 1945). The possession of idiosyncratic information allows people to see particular opportunities that others cannot see, even if they are not actively searching for such opportunities. Differences in information lead people to see different value in a given good or service and offer different prices to obtain it. By buying or selling goods and services in response to the discovery of price misalignments, an individual can earn entrepreneurial profits or incur entrepreneurial losses. Collectively, this process

of decision making about prices moves an economy from disequilibrium to equilibrium. In short, Austrian theories assume that (1) people cannot recognize all entrepreneurial opportunities; (2) information about opportunities, rather than fundamental attributes of people, determine who becomes an entrepreneur; and (3) this process depends on factors other than people's ability and willingness to take action.

The Implications of the Differences

Empirical investigation of the Austrian perspective on entrepreneurship is important because the Austrian framework provides different explanations for the discovery, exploitation, and organization of entrepreneurial opportunities from those provided by neoclassical economic and psychological frameworks. First, unlike neoclassical economic theory, Austrian economics does not view the process of opportunity discovery as mechanical. Neoclassical economics' assumption of public knowledge about opportunities means that all opportunities must be equally ''obvious'' to everyone. Because any given entrepreneur *can* discover the complete set of opportunities that occur in response to a given technological change, neoclassical economics argues that entrepreneurs select between different opportunities through a process of maximization (Khilstrom and Laffont 1979, Evans and Jovanovic 1989). However, Kirzner (1973, p. 33) explains that once the assumption of complete information is relaxed, the discovery of opportunity cannot be understood through ''mechanical computation'' because any given individual cannot identify all possible opportunities. If any given entrepreneur cannot necessarily discover more than one commercial application for any given technological change, then entrepreneurs cannot actively select (let alone maximize) between alternative opportunities (Kirzner 1985).

Second, unlike both neoclassical economics and psychology, Austrian economics provides an explanation for the entrepreneurial process that does not depend on the identification of people who are more likely than other people to become entrepreneurs. Because the Austrians believe that the possession of information that is appropriate to a particular opportunity leads to opportunity discovery, they do not believe that anyone is more likely than anyone else to become an entrepreneur *across all opportunities*. This distinction is important because the episodic nature of entrepreneurship makes stable attributes an unlikely explanation for people's decision to become entrepreneurs (Carroll and Mosakowski 1987). Moreover, no individual-level attributes or behaviors have been found to generate significant differences between entrepreneurs and other members of society that are robust, consistent across different samples, or explain much variance (Busenitz and Barney 1997).[1]

Third, unlike both neoclassical economics and psychology, Austrian economics considers opportunity exploitation to be endogenous to opportunity discovery. Much of the existing empirical evidence on opportunity exploitation has assumed that the attributes of people who discover opportunities are uncorrelated with the attributes of the opportunities that they discover (Evans and Jovanovic 1989). Researchers making this assumption have studied how individual differences affect the way people exploit opportunities while ignoring attributes of the opportunities themselves. However, if human attributes are correlated with the opportunities that people discover, then these researchers have confounded attributes of entrepreneurs and opportunities in empirical tests of who is an entrepreneur (Venkataraman 1997). For instance, studies comparing entrepreneurs to managers that do not consider whether individual differences influence the opportunities discovered (e.g., Kaish and Gilad 1991, Chen et al. 1998) cannot tell whether entrepreneurs differ from managers because they possess different attributes or because entrepreneurs are responding to valuable opportunities and managers are not.

Fourth, the Austrian explanation for entrepreneurship generates different implications from the other two frameworks for who becomes an entrepreneur, how entrepreneurial efforts are organized in the economy, and how the government can influence the entrepreneurial process. For example, neoclassical economists have argued that general purpose technologies should be exploited by a single entrepreneur across different market applications because such centralization minimizes duplication of effort and contracting costs, and increases economies of scale and scope (Bresnahan and Trajtenberg 1995). However, if people do not discover the same entrepreneurial opportunities in a given new technology, then decentralized commercial exploitation of general purpose technologies is advantageous. Centralization of new technology development will lead to underidentification of opportunities because no central agent can identify all possible entrepreneurial opportunities for a new technology (Nelson 1987).

Given the importance of explaining opportunity discovery to our understanding of the entrepreneurship process, empirical evidence that supports or refutes the Austrian perspective on the discovery process is important. In the next section, I generate specific propositions from the Austrian framework, which I then examine empirically.

Conceptual Model and Propositions

Information Asymmetry and the Nonobviousness of Opportunity

Entrepreneurial opportunities are opportunities to bring into existence new goods, services, raw materials, and organizing methods that allow outputs to be sold at more than their cost of production (Casson 1982). These opportunities exist because different people possess different information (Kirzner 1997). Incomplete information means that in any market transaction, people must guess each other's beliefs about many things (Kirzner 1973). Because these guesses can be incorrect, this process sometimes leads to errors that misallocate resources. The entrepreneurial process occurs when someone, alert to this misallocation, recognizes that resources are not being put to their ''best use,'' obtains the resources, recombines them, and sells them at more than they cost to obtain and recombine (Casson 1982).[2]

People do not recognize the value of all opportunities, thus allowing entrepreneurs to obtain resources at below their equilibrium price (Venkataraman 1997). If resource owners recognized the same opportunities that entrepreneurs discovered, they would want to appropriate the entrepreneurial profit by selling (or renting) their resources to the entrepreneur at the price that would leave the entrepreneur with just enough profit to act (Casson 1982). Moreover, if all potential entrepreneurs recognized the same opportunities, they would compete for the profit. This competition would lower each entrepreneur's share of the entrepreneurial profit to the point at which it did not provide potential entrepreneurs with an incentive to act (Fiet 1996).

Given that information asymmetry is necessary for entrepreneurial opportunities to exist, everyone in society must not be equally likely to recognize all opportunities. Rather, only a subset of the population is able to recognize any particular opportunity at any particular point in time (Kirzner 1973). The above argument leads to the first proposition.

PROPOSITION 1. *All individuals are not equally likely to recognize a given entrepreneurial opportunity.*

The Discovery Process

Before an individual can earn an entrepreneurial profit from an opportunity, he or she must discover that it has value. Two alternative explanations exist for this discovery process: search and recognition. Several authors (e.g., Stiglitz 1994) have argued that opportunity discovery depends on relative differences in search costs among potential entrepreneurs. The search model assumes that people know the outcomes for which they are searching and search when the benefit of the information outweighs the cost of obtaining it (Stigler 1961). Several empirical entrepreneurship researchers have incorporated this approach into their theories of entrepreneurship (see Baron, forthcoming; Shaver and Scott 1991). They argue that people discover opportunities because their superior information processing ability, search techniques, or scanning behavior make them more likely than other people to discover opportunities (Shaver and Scott 1991).

Austrian economists have challenged this approach, arguing that people do not search for entrepreneurial opportunities because ''opportunity, *by definition*, is unknown until discovered''; and one cannot search for something that one does not know exists (Kaish and Gilad 1991, p. 38). Kirzner (1997, p. 71–2) explains that

> An opportunity for pure profit cannot, by its nature be the object of systematic search. Systematic search can be undertaken for a piece of missing information but only because the searcher is aware of what he does not know and is aware with greater or lesser certainty of the way to find out the missing information . . . . But it is in the nature of an overlooked profit opportunity that it has been utterly overlooked, i.e., that one is not aware at all that one has missed the grasping of any profit . . . . What distinguishes *discovery* (relevant to hitherto unknown profit opportunities) from *successful search* (relevant to the deliberate production of information which one knew one had lacked) is that the former (unlike the latter) involves the *surprise* that accompanies the realization that one had overlooked something in fact readily available.

The above argument suggests that people do not discover entrepreneurial opportunities through search, but through recognition of the value of new information that they happen to receive through other means. The discovery of opportunities in the absence of search is an important part of the Austrian framework because it explains why entrepreneurship is not solely a function of differences in human ability or willingness to take action (Kirzner 1997). The above argument leads to the second proposition.

PROPOSITION 2. *People can and will discover entrepreneurial opportunities without actively searching for them.*

Prior Knowledge and the Discovery Process

Why do people discover some entrepreneurial opportunities and not others? One answer is that people recognize those opportunities related to information that they already possess (Venkataraman 1997). People have different stocks of information because information is generated through people's idiosyncratic life experiences. Moreover, because information is often distributed

through a stochastic process, some people possess information that others do not have through blind luck (Nelson and Winter 1982). As a result, at any given time only some people, and not others, will know about particular customer problems, market characteristics, or the ways to create particular products or services (Venkataraman 1997).

Each person's idiosyncratic prior knowledge creates a ''knowledge corridor'' that allows him/her to recognize *certain* opportunities, but not others (Venkataraman 1997). Prior information, whether developed from work experience, education, or other means, influences the entrepreneur's ability to comprehend, extrapolate, interpret, and apply new information in ways that those lacking that prior information cannot replicate (Roberts 1991). Therefore, even if information about a technological change is disseminated broadly—particularly if it is disclosed in a patent, presented at a scientific conference, or known to several individuals who might work in the same laboratory—only some subset of the population will possess prior information that will trigger the discovery of a particular entrepreneurial opportunity. Three major dimensions of prior knowledge are important to the process of entrepreneurial discovery: prior knowledge of markets, prior knowledge of ways to serve markets, and prior knowledge of customer problems.

New information about a technology might be complementary with prior information about how particular markets operate, leading the discovery of the entrepreneurial opportunity to require prior information about those markets. Important prior knowledge about markets might include information about supplier relationships, sales techniques, or capital equipment requirements that differ across markets (Von Hippel 1988). For example, a person who had previously worked in a market as a customer, manufacturer, or supplier might already possess information that is not publicly available about how a new technology might influence that market. This prior information enables him or her to discover an opportunity in which to use the new technology (Roberts 1991). The above argument suggests the following proposition:

PROPOSITION 3a. *People's prior knowledge about markets will influence their discovery of which markets to enter to exploit a new technology.*

New information about a technology might be complementary with information about ways to serve markets, leading the discovery of the entrepreneurial opportunity to require prior information about these processes. An entrepreneur's ability to recognize an opportunity in a new technology might be enhanced by prior knowledge about *how* the new technology could be used to create a product or service. A new technology might change a production process, allow the creation of a new product, provide a new method of distribution, permit new materials to be used, generate new sources of supply, or make possible new ways of organizing (Schumpeter 1934, p. 66). These different dimensions of opportunity necessitate different organizational and production decisions about how to serve a market (Von Hippel 1988).

Recognizing these alternatives is difficult absent some prior knowledge of how they relate. Therefore, Aldrich and Wiedenmayer (1993) explain that the forms of new organizations and the product or service lines that entrepreneurs establish are related to the organizational units in which they previously worked. In addition, Boeker (1988) explains that the functional background of semiconductor manufacturers influences the strategy that entrepreneurs adopt in their new firms. The above argument suggests the following proposition.

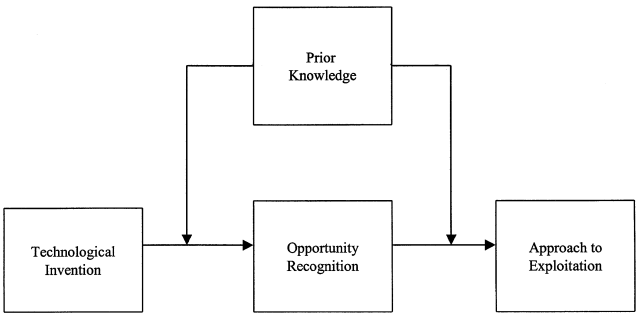
PROPOSITION 3b. *People's prior knowledge about how to serve markets will influence their discovery of how to use a new technology to serve a market.*

New information about a technology might be complementary with prior information about a customer problem, such that discovery of the entrepreneurial opportunity might require prior information about customer needs. The locus of innovation often lies with the user of a new technology because users cannot articulate easily their needs for not-yet-developed solutions to problems (Von Hippel 1994). Unless the recipient of technical information already shares much of the same tacit knowledge as the transmitter, knowledge transmission is either impossible or prohibitively costly (Cohen and Levinthal 1990). Individuals who lack familiarity with the customer's problem find it difficult to recognize solutions to those needs when the solutions come along (Roberts 1991). This process leads entrepreneurs to start new companies to solve customer problems that they learned from working with users in their previous employment (Von Hippel 1988). The above argument suggests the following proposition.

PROPOSITION 3c. *People's prior knowledge of customer problems will influence their discovery of products and services to exploit a new technology.*

The conceptual model described above is summarized in Figure 1. The figure illustrates that prior knowledge moderates the relationship between the attributes of a technology and the recognition of entrepreneurial opportunities. It also illustrates that prior knowledge moderates the relationship between the attributes of the opportunity

Figure 1 Conceptual Model



as recognized and how the entrepreneur chooses to exploit the opportunity.

Research Design

This article reports the results of a detailed field study of eight actual business opportunities to exploit a single MIT invention: the three-dimensional printing (3DP™) process.

The Technology[3]

The three-dimensional printing (3DP™) process is a patented manufacturing technology, invented in 1989 by four MIT faculty and doctoral students under the lead of Professor Ely Sachs. According to the abstract of the patent, the 3DP™ process is ''a process for making a component by depositing a first layer of a fluent porous material, such as a powder, in a confined region and then depositing a binder material to selected regions of the layer of powder material to produce a layer of bonded powder material at the selected regions. Such steps are repeated a selected number of times to produce successive layers of selected regions of bonded powder material so as to form the desired component. The unbonded powder material is then removed. In some cases the component may be further processed as, for example, by heating it to further strengthen the bonding thereof.''

Procedure

I used a case study design to examine the eight new venture opportunities to exploit the 3DP™ process. The case study design allows investigation of how opportunity discovery operates in a real-world environment in which decisions actually take place, provides evidence in a situation in which all of the relevant behaviors cannot be manipulated through experimental design, and allows the incorporation of a variety of different sources of evidence, including both archival documents and interviews (Yin 1984).

In late 1997 and early 1998, I conducted an in-depth field study of the eight entrepreneurial opportunities, which involved a set of field interviews with the entrepreneurs, their investors, and others involved in the evaluation or exploitation of the opportunities. The interviews were unstructured and lasted from one-half hour to three hours. The interviews typically began with an invitation to describe how the entrepreneur learned of the 3DP™ process. With many respondents, I conducted follow-up interviews and phone calls to clarify issues. For each interview, I tape-recorded the conversation and then worked from the tape transcriptions. In total, I conducted 30 hours of interviews with 22 individuals.

In qualitative case study research, corroboration of interviews through the use of archival records is important to validate information (Yin 1984). Therefore, the interview data were supplemented with information from other sources. I had access to MIT Technology Licensing Office (TLO) files on the entrepreneurs, which included copies of business plans, press releases, contracts, product information, and correspondence. I conducted Diolog, Lexis-Nexis, and ABI Inform searches for articles about the companies and entrepreneurs. I also obtained venture capital and other financing records on the companies from database providers. Finally, I conducted patent and article citation searches on the companies and entrepreneurs.

An embedded case study design, in which the unit of analysis was the entrepreneurial opportunity, was used to analyze the data. Following Yin (1984), separate case studies on each of the eight opportunities were developed from the interviews, database information, and archival records. Reliability was established through the development of a case study protocol and a case study database (Yin 1984). The case study protocol included the use of ''table shells'' to record data (Miles and Huberman 1984). These outlines ensured that the data collection was focused on the process of opportunity discovery, verified that the same information was being collected for all cases, and aided in the data analysis. Construct validity was established by using multiple sources of evidence, the creation of a chain of evidence, and by having key informants review drafts of the case study report (Yin 1984).

Pieces of information from the cases were compared to the propositions to determine the degree to which they were consistent, following the pattern matching logic recommended for case study design (Miles and Huberman 1984). The pieces of information were also compared to rival, mutually exclusive propositions to determine the degree to which they were inconsistent with alternative explanations since case studies support a proposition if the pieces of evidence uncovered are consistent with the

proposition but inconsistent with alternative mutually exclusive explanations (Yin 1984).

Sample

Like all MIT inventions, the 3DP™ process was available for commercialization through license from the TLO. The TLO grants three types of licenses: exclusive licenses to use an invention in all fields of use, exclusive licenses to use an invention in a particular field of use, and nonexclusive licenses to use the invention. The decision of which type of license to establish is made during the process of evaluation by potential licensees and is a function of several factors: the type of license requested, the types of licenses that have already been granted, the amount of money the licensee is willing to pay, the licensing officer's judgment about how the technology should be exploited, and any government or university policies that would restrict the commercialization of the technology. Licenses are typically granted after the entrepreneurs have conducted preliminary investigation of the technology. During the preliminary investigation, the entrepreneurs are required to maintain confidentiality. For this reason, the TLO maintains excellent records on all entrepreneurs who have investigated MIT inventions, whether or not they ultimately license to them.

The TLO licensed the rights to use the 3DP™ process to four teams of entrepreneurs who have created new companies to exploit this technology in different fields of use. The TLO also has records of four teams of entrepreneurs who discovered and investigated entrepreneurial opportunities to exploit the 3DP™ process, but who failed to start companies. Because all eight sets of entrepreneurs discovered entrepreneurial opportunities for the same invention, comparison of these opportunities allows me to explore the differences in business opportunities discovered by different entrepreneurs in response to the same new technology. Table 1 shows the eight ''companies,'' the entrepreneurs, and the opportunities that they discovered. Astute readers will note that none of the four inventors of the 3DP™ process chose to exploit this technology by starting a new company.

Z Corp. Z Corp was founded by Marina Hatsopoulos, Walter Bornhorst, Jim Bredt, and Tim Anderson to manufacture a fast, inexpensive, office-compatible machine to make three-dimensional concept models for engineering and architectural design. Design engineers and architects use concept models to review design changes early in the design process and to present ideas to others who cannot read CAD designs, but who are involved in the design process. The Z Corp machine makes rapid prototypes 20 times faster than existing rapid prototyping processes and out of less expensive materials, reducing the cost of prototyping, accelerating the process, and allowing for more design iterations.

Therics. Therics was founded by Walter Flamenbaum to manufacture drug delivery systems for the pharmaceutical industry. The 3DP™ process allows one to control the amount, time, and sequence of drug delivery. This allows drugs to be delivered in a way that ensures optimum blood drug levels, increasing drug efficacy and reducing side effects as compared to alternative drug manufacture processes.

Specific Surface Corporation. Specific Surface was founded by Andrew Jeffery and Mark Parish to manufacture ceramic filters for the power generation market directly from computer drawings without tooling, dies, or molds. The 3DP™ process allows Specific Surface to manufacture filters with geometries and performance not possible with alternative processes. This allows them to provide customers with filters that more efficiently remove particulates from dirty hot flue gas streams, and thereby provides customers with greater power generation efficiency.

Soligen. Soligen was founded by Yehorem Uziel to provide foundries with the ability to postpone the design and creativity of casting tooling until after the design is proven thus eliminating the need to prototype tooling. Soligen's Direct Shell Production Casting (DSPC) is based on the 3DP™ process and allows Soligen to make a ceramic mold directly from a CAD model, using a powder and binder, without the need for wax forms or tooling. This technology allows Soligen to develop cast metal parts with a much shorter lead time and at a lower investment cost than is the case with existing technology, allowing customers to speed product introduction.

3D Partners. Andrew Kelly proposed using the 3DP™ process to a create a service bureau to provide architectural models. Currently, architectural models are made by hand in a time intensive manner that requires significant craft experience. Using the 3DP™ process, this business would receive CAD drawings electronically and then send back finished architectural models faster and at a lower cost than existing alternatives.

3D Orthopedics. Stephen Campbell proposed using the 3DP™ process to provide custom-fitted orthopedic devices for the medical and dental market. Currently, diseased or injured bones must be replaced with cleaned cadaver bones, bone harvested from another part of the body, or prefabricated artificial substitutes. The 3DP™ process allows three-dimensional forming of a biologically compatible replacement bone that could be printed out of any material and implanted.

Table 1 The Companies and Dimensions of the Opportunities

Company	Entrepreneurs	Opportunity	Forecast Market Size in Year 5	Forecast Sales in Year 5	Forecast EBIT	Current Status
Z Corp	Marina Hatsopoulos Walter Bornhorst Jim Bredt Tim Anderson	Manufactures a fast, inexpensive, office-compatible machine to make concept models for industrial and architectural design	$100 million	$10 million	$2 million	Private company funded by founders
Therics	Walter Flamenbaum	Manufactures pills with a superior microstructure through a fully integrated manufacturing process	$9 billion	$2 million	−$7.5 million	Private company funded by venture capital
Specific Surface	Mark Parrish Andrew Jeffrey	Manufactures ceramic filters for the power generation market in a one-step manufacturing process	$800 million	$31.5 million	$13 million	Private company funded by venture capital
Soligen	Yehorem Uziel	Manufactures machines to make ceramic molds for casting metal parts directly from a CAD model without wax forms or tooling	$20 billion	$50 million	$8.5 million	Public company
3D Partners	Andrew Kelly (and others)	Creates a service bureau to produce architectural models from CAD drawings	$10 million	Never done	Never done	Abandoned when market found too small
3D Orthopedics	Stephen Campbell	Provides a service to create artificial bone for weight bearing indications for use in surgery	Never done	Never done	Never done	Abandoned when not funded by venture capital
3D Imaging	Lau Christianson Todd Jackson	Provides a service to create multicolor, three dimensional surgical models	Never done	Never done	Never done	Abandoned when lost 50K business plan competition
Conferences	Michael Padnos	Establishes a chain of stores to make sculptures from photographs	Never done	Never done	Never done	Abandoned when technology found inappropriate

3D Imaging. Lau Christianson and Todd Jackson proposed using three-dimensional printing to provide a modeling service for surgeons. Currently, surgeons must abstract from two-dimensional CAT scans and MRI images when planning for surgery. The 3DP™ process would allow the creation of multicolor, three-dimensional models of the human brain for surgical planning that would reduce error and malpractice exposure.

Conferences. Michael Padnos proposed using the 3DP™ process to establish a chain of stores to make three-dimensional heads and busts of people. Currently, people purchase a large number of photographs of family and friends. The 3DP™ process would create three-dimensional sculptures for consumers from these photographs.

Results

All Individuals Are Not Equally Likely to Recognize a Given Opportunity: Examining Proposition 1

Although many people were exposed to information about the invention of the 3DP™ process, very few entrepreneurial opportunities to exploit the technology have been discovered. Since its invention in 1989, 3DP™ has been described in patent applications, conference presentations, publications, a website, MIT technology licensing office mailings, and industry consortium meetings. Several trade and popular publications—including *Fortune*, the *Financial Times*, and the *Economist*—have written stories about it. Yet only eight entrepreneurial opportunities for the 3DP™ process have been discovered.

The number of entrepreneurs who discovered entrepreneurial opportunities in the 3DP™ process was limited because opportunities are not obvious from information about the 3DP™ process alone. As Table 2 shows, in none of the eight cases did the respondents indicate that the opportunities were obvious from simple observation of the 3DP™ process. For example, Walter Flamenbaum (Therics) explains that MIT's 3DP™ process was far from medically acceptable and not based on good manufacturing principles:

> All of the 3DP lab's work was in one ceramic powder and one fluid, and medical applications require multiple fluids and multiple powders, specifically polymers. You couldn't just look at the 3DP™ process and know that you could use it for medical purposes. To make use of 3DP™ process for drug delivery, you had to know something about what drugs and drug delivery systems are made from and how drug manufacture operates.

Moreover, none of the entrepreneurs examined any of the other opportunities to use the 3DP™ process before other entrepreneurs had disclosed them. As Marina Hatsopoulos (Z Corp) explains:

> I absolutely could not have seen the business concepts that the other licensees were doing . . . . I knew nothing about casting . . . . Also, you could not make metal parts using the 3DP™ process the way we use it . . . . You would have to think of a different way to use the machine. What Specific Surface is doing would never have occurred to me. And I don't think that it would have ever have occurred to me in a thousand years that you could print pills . . . like Therics does.

Consequently, none of the eight sets of entrepreneurs discovered more than one opportunity in which to use the 3DP™ process, despite differences in the market size, potential returns, or resulting outcomes of those opportunities. They also did not weigh the relative advantages and disadvantages of using the technology to pursue different opportunities.

It is important to note that the evidence presented in Table 2 and in the text above does not preclude the dissemination of new knowledge about inventions from influencing the discovery of opportunity. People who learn

Table 2 The Nonobviousness of Opportunity

Company	Examples of the Respondents' Descriptions of the Obviousness of the Opportunity, Not Quoted in the Text
Z Corp	"I certainly never would have thought that someone would make pills with the 3DP™ process." —Walter Bornhorst
Specific Surface	"All Ely Sachs had was a small machine putting out something maybe every two days. This was not something that you would think, we can use this for manufacturing. It wasn't clear that the binder MIT was using was compatible with chemical binder systems to make ceramic filters, but we didn't think that the binder was limited to MIT's binder. Also, to make filters you have to have to be able to produce something of very high quality. It has to have high building integrity, cannot have any holes, and must hold together in a very hot environment. The MIT process did not worry about any of those things. In addition, the MIT researchers were not focusing on the creation of a finished product, they were focusing on the creation of molds and prototypes that were intermediate steps. Moreover, they were emphasizing accuracy and precision, which were not the exact areas of emphasis for our needs."—Andrew Jeffrey
Soligen	"They had a single jet printing machine, and the printer jet was something that MIT made from a syringe . . . . There was no way to make a commercial machine with a single jet. To develop DSPC, one actually had to use a different and a substantially faster printing technology. The only thing that we used is the concept of printing liquid on to sequential layers of powder."—Yehorem Uziel
3D Partners	"The insight came from familiarity with architectural study models. It wasn't even obvious to the rest of us."—Andrew Kelly
3D Orthopedics	"To know that the 3DP™ process can be used to create artificial bone, one has to have a sense of the materials to combine in the creation of the composition and the biology of the human system. Moreover, one has to know the microstructural aspects of bone, artificial bone replacements as well as the emerging field of 3D imaging."—Stephen Campbell
3D Imaging	"We just looked at . . . what can you do with multiple materials and we saw something different from the other entrepreneurs. We had no idea that you could use three dimensional printing for orthopedic applications, ceramic casting, or to make filters. Neither of us knows anything about ceramic filters or investment casting . . . . I did not have the background to understand mechanical uses . . . ."—Lau Christianson
Conferences	"You had to know something about why people take photographs to see the opportunity to use this technology to convert photographs to sculptures."—Mike Padnos

about new knowledge before others may be more likely to discover opportunities to make use of that new knowledge. In the interest of space, however, this paper held the dissemination of new knowledge constant and explored only the influence of the distribution of prior knowledge on the ability to recognize it. Therefore, this study draws no conclusions about the effect of the dissemination of information on the discovery process.

The Process of Discovery: Examining Proposition 2

As Table 3 shows, the eight entrepreneurs also described a discovery process which involved recognition, rather than a search for information. In none of the cases did an entrepreneur indicate that he or she was searching for the opportunity prior to its discovery. For example, Mike Parrish (Specific Surface) explains, ''When Mike Cima showed me MIT's 3DP machine, I just thought that this would make great filters . . . . The point is, we never searched for this opportunity.''

Moreover, none of the entrepreneurs had contacted the TLO about a previous technology. Rather, each of the entrepreneurs heard about the technology from someone directly involved in its development, and recognized the opportunity *immediately* upon hearing about it. For example, Yehorem Uziel (SOLIGEN) explains, ''When Ely Sachs showed me MIT's 3DP™ process, I just saw immediately that there was an opportunity to make functional metal parts directly from a computer.''

When asked why they were able to discover opportunities when they were not searching for them, the respondents offered answers consistent with Austrian economics. In all eight cases, the respondents indicated that they simply recognized the opportunity, almost by accident, as if they were surprised by the discovery. For example, Walter Flamenbaum (Therics) explains:

> If Bob Cohn, who has been responsible for drug delivery systems and product development at J&J had looked at it, it would have been different . . . . [H]e would have turned around and said, 'holy cow!' This is a platform that's wonderful for drug delivery systems. If you had showed to someone who does tissue engineering, they would have said, 'holy cow!' This is wonderful for tissue healing matrices for our biological development of tissues and organs. It's a matter of mind set and background.

The results also provide evidence that is inconsistent with the argument that these entrepreneurs discovered opportunities because they are better than others at searching for and discovering opportunities *in general*. If this were the case, then the eight sets of entrepreneurs described here should have been more likely than other people but equally likely to each other to discover *all* the opportunities. The empirical observation that each of them was inferior at opportunity discovery for seven out of the eight opportunities suggests that superiority at the discovery process *alone* is not sufficient to explain the discovery of opportunity. Rather, it suggests that such superiority is situation-specific.

The Influence of Prior Knowledge on the Discovery of the Market: Examining Proposition 3

Table 4 summarizes the relationship between different dimensions of the entrepreneurs' prior knowledge and their entrepreneurial efforts. As Table 4 indicates, all eight sets of entrepreneurs used the 3DP™ process in different markets, served the market in different ways,

Table 3 The Process of Discovery

Company	Examples of Respondents' Descriptions of the Discovery Process, Not Quoted in the Text
Z Corp	''The value it had just made sense to me when I saw the MIT machine. It was instinctive, just like if you showed someone who uses a typewriter this invention called a word processor. I saw the opportunity before I did any market research and learned that yes, indeed, people would buy this product.''—Marina Hatsopoulos
Therics	''We sat around a room and talked about the process. For whatever reason—and I think you need to go to your friends who do cognitive theory to find an answer—I just intuitively saw the opportunity in chronopharmacology. I certainly wasn't searching for the opportunity.''—Walter Flamenbaum
3D Partners	''He was just working in the lab and saw these little rocker arms we make and the idea came to him.''—Andrew Kelly
3D Orthopedics	''Mike Cima showed me the 3DP™ process one day and my idea to make orthopedics just clicked.''—Stephen Campbell
3D Imaging	''When we started talking about what we could do with the 3DP™ process, I immediately thought of my research and how I could combine what I knew with it.''—Todd Jackson
Conferences	''I just looked at the machine and thought about what could be done with it on a consumer level. My idea came to me immediately.''—Mike Padnos

Table 4 The Relationship Between the Dimensions of the Opportunities and Prior Knowledge

Company	Market	Prior Knowledge of Market	Means to Serve	Prior Knowledge of Means to Serve	Solution to Problem	Prior Knowledge of Solution to Problem
Z Corp	Industrial Design and Architecture	(a) Education and work experience in industrial design (b) work experience in architecture	Manufacture machine to make concept models	Knowledge of machine design and manufacture from education	Cheap, fast on-site production of concept models	(a) Work experience with cannibalized computers showed value of ink-jet print head; (b) Materials education showed the value of low cost starches
Therics	Pharmaceuticals	Work experience in pharmaceutical industry	Manufacture of drugs with special microstructure through creation of FDA-approved machine	(a) Work experience with drug materials; (b) work experience with FDA approval and scale-up in pharmaceuticals	(a) Drug micro structures that control amount and timing of drug release; (b) Easier government approval of scale-up	(a) Research on hypertension showed "wet mass" drug release problem; (b) Work experience in drug approval showed scale-up approval problem
Specific Surface	Power Generation	Work experience supplying filters for power plants	Manufacture finished ceramic product on modified Soligen machine	(a) Education and work experience in ceramics; (b) Work experience with minimizing the manufacturing process; (c) Lack of experience and education in machine manufacture	Efficient ceramic filters with better geometries that withstand high stress and hot temperatures	(a) Work experience and education showed how 3DP process would solve problems with filter geometry; (b) Work experience and education showed how to make uniform porosity ceramics
Soligen	Metal casting	Work experience supplying prototyping machines to users of metal parts	Manufacture machine to make ceramic molds for metal casting	Knowledge of machine design and manufacture from work experience	Manufacture of functional metal parts without expensive tooling	Knowledge of stereolithography showed problems in using plastics for mockups and production
3D Partners	Architecture	Work experience in architecture	Service bureau for architecture models using Z Corp machine	(a) No knowledge of manufacture of machines; (b) Work experience in architecture concept model creation	Speed up and lower cost of creating concept models	Prior experience making architectural models showed problems with craft approach

Table 4 (continued) The Relationship Between the Dimensions of the Opportunities and Prior Knowledge

Company	Market	Prior Knowledge of Market	Means to Serve	Prior Knowledge of Means to Serve	Solution to Problem	Prior Knowledge of Solution to Problem
3D Orthopedics	Orthopedics	Education and work experience in prosthodontics	Service to provide custom artificial bone from MRI images	(a) Education and work experience in prosthodontics; (b) Research with imaging technologies; (c) Work experience as surgeon	Artificial bone for weight bearing indications	Research on 3-D models of bones, education in ceramics, and work experience in surgery showed problem of replacing bone
3D Imaging	Surgical Models	Work experience in health care consulting	Service to provide surgical models	(a) Work experience in health care consulting; (b) Research on CAD interface with 3DP	Multicolor 3D models	Research on CAD interface showed problems making three dimensional objects in multiple colors
Conferences	Retail consumer goods	(a) Work experience as art dealer; (b) Personal experience as art collector	Retail stores in malls to make sculptures	(a) No knowledge of machine manufacture, or industrial products; (b) Experience in retail	Sculptures from photos	Prior personal experience showed people go to malls to buy photos

and used the 3DP™ process to provide solutions to different customer problems. In each case, the selection of the market, the way to serve the market, and the solutions to the customer problems were influenced by the entrepreneur's prior knowledge.

While the eight cases show that prior knowledge influences the discovery of opportunity, they also show that many types of prior information influence this process. As Venkataraman (1997) argued, the sources of the prior knowledge that lead to opportunity discovery are idiosyncratic, resulting from work experience, personal events, and education. Moreover, this prior knowledge can be developed through a variety of roles, including experience as a supplier, user, and manufacturer, and education on a variety of dimensions, such as production processes, inputs, and user needs.

Identification of the Market. As Table 5 shows, all eight sets of entrepreneurs discovered markets about which they had prior knowledge. For example, Z Corp's entrepreneurs discovered the industrial design and architectural markets because Marina Hatsopoulos (Z Corp) and Walter Bornhorst (Z Corp) had developed prior knowledge of these markets through education and work experience. Both Marina and Walter were trained at MIT as mechanical engineers and had studied industrial design, which enabled them to see the industrial design market for the 3DP™ process.

Marina and Walter's previous experience in the architectural market also led them to see the applications of the 3DP™ process in that market. Prior to founding Z Corp, both Walter and Marina had undertaken major real estate rehabilitations, in which they participated in the architectural layout and interior and exterior design. Because of their experience in both the industrial design and architecture markets, Z Corp's entrepreneurs discovered a $100 million market for the 3DP™ process.

In contrast, the limited prior knowledge of the entrepreneurs who founded 3D Partners led them to recognize only the architectural market in which to use the 3DP™ process. Andrew Kelly (3D Partners) explains:

> [The person who discovered the opportunity] was an architect . . . . We focused on . . . the architectural market because it was the only market we knew anything about . . . . We did not know anything about any other markets . . . . [But] the architectural model making industry nationwide is only $10 million, that's too small to build a company.

Yehorem Uziel's (Soligen) prior work experience also led him to recognize the usefulness of the 3DP™ process

Table 5 The Selection of the Market

Company	Examples of Respondents' Descriptions of the Selection of the Market, Not Quoted in the Text
Z Corp	"The value of the 3DP™ process to rapid prototyping inherently made sense to me because I've done design on a computer screen and I know how difficult it is to visualize a three-dimensional model. For my thesis at MIT, I had to do a very simple design. Even so, it was really a challenge doing all the drawings. It would have been easier to see what the device would look like before I went ahead and actually built it. I also took this composites class and we had to design a chair using composite materials. I thought it would be really neat to see what it would look like. So I actually built a model out of foam core and string so I could understand my own design. I had this burning desire to have that 3D model as I was doing the design . . . . It was natural to think of the architectural market because of my personal experience. I've done a lot of architectural design. We've done renovations of buildings and in all those cases there are certain views that get really tricky to visualize from a two-dimensional diagram. Architects are designing very much in three dimensions and so for them, three-dimensional models are useful. Even more importantly, architects are interacting with lay people who want to build a golf course or a house or whatever and cannot read a CAD drawing at all."—Marina Hatsopoulos
	"I immediately recognized how valuable it would be to have an object in front of me when I'm trying to sort out a three-dimensional problem . . . because I have struggled with trying to visualize three-dimensional things when I'm trying to design something myself."—Walter Bornhorst
Therics	"I had enough commercial experience in the pharmaceutical industry that I know what the markets are. I know about drug delivery systems and thought about the percentage of that market that were for drugs that would benefit from chronopharmacologic drug delivery. I knew that there were some huge markets like hypertension and angina that you could clearly capture."—Walter Flamenbaum
Specific Surface	"The market was always filters for power plants . . . . I was working in gas filtration when I saw the 3DP™ process . . . and I knew that large companies were looking for ways to improve the efficiency of ceramic filters. I knew that people at ABB and Westinghouse were working on this issue."—Andrew Jeffrey
Soligen	"I was first introduced to the 3DP™ process when I was . . . at 3D Systems and was working on rapid prototyping machines for Ford . . . . Work with the automakers made me aware of the benefit of a machine that can make functional metal parts . . . . For example, if you are Ford or GM and you are developing a new engine and [you have] a lot of iterations at the beginning of the process . . . you gain by avoiding . . . temporary tooling to do the casting . . . . If you can delay the creation of expensive artwork until after you know that there are no changes so you can get the production tooling right the first time, that's a big thing . . . . So I was looking at undertaking a revolution in the metal casting industry way before I even heard of Ely Sachs and Mike Cima."—Yehorem Uziel
3D Orthopedics	"I knew from the outset that there was a market to use the 3DP™ process to replace bones and teeth. My specialty is prosthodontics, which means replacement of body parts with artificial substitutes. I was treating patients and running an advanced education program at The Harvard School of Dental Medicine in this area at the time I learned about the 3DP™ process. Before that I went to dental school at Virginia and then did a specialty training program in prosthodontics at Harvard, with advanced materials training at MIT."—Stephen Campbell
3D Imaging	"I have done a fair bit of work in health care economics and exploring different health care products. I was familiar with health care markets and could speak about what goes on there. I knew that MRI and CAT scan came out in three-dimensional form. I also knew about health care trends and that there was a market for things to improve surgery. Finally, I knew that neurosurgeons are very technology friendly and would be interested in anything that could possibly make their lives easier and make the surgery go more smoothly."—Lau Christianson
Conferences	"I have no knowledge of any industrial markets . . . but an understanding of consumer markets. So, when I looked at the 3DP™ process, I saw the consumer applications."—Mike Padnos

to a particular market. However, unlike Z Corp's founders, he developed this knowledge from his experience as a supplier rather than as a user. Because he served as vice president of engineering at 3D Systems, a rapid prototyping manufacturer, Yehorem recognized the usefulness of the 3DP™ process to the investment casting industry. As a supplier to Ford, General Motors, and Chrysler, he learned that users of metal parts make hundreds of thousands of models and prototypes per year, that they spend double the time on design tooling as they

do on production tooling, and that they spend weeks on making prototypes that the 3D process can make in a matter of days.

Like Yehorem Uziel, the founders of Specific Surface Corporation selected their market because of prior work experience as a supplier to a market. Andrew Jeffery's prior experience in product development as a supplier of filtration media for coal burning power stations led him to recognize the usefulness of the 3DP™ process to the power generation market. Because his previous job required him to identify new market opportunities for industrial filtration, Andrew became aware that ABB and Westinghouse were searching for more durable and more efficient ceramic filters to remove hot flue gas of particulates in response to recent environmental regulation.

Like the previous sets of entrepreneurs, Walter Flamenbaum's (Therics) selection of a market was influenced by his prior work experience. However, in Walter's case, the prior knowledge was developed not as a user or supplier, but as a manufacturer. Walter selected the pharmaceutical industry in which to use the 3DP™ process because 25 years of experience in product development and regulatory approval in that industry led him to see the usefulness of the 3DP™ process to that market.

Stephen Campbell (3D Orthopedics) recognized the usefulness of the 3DP™ process to a specific market because of his prior work experience *and* education. He attributes his discovery of the market to his advanced materials training at MIT and his work experience in prosthodontics. He explains:

> I knew about the new imaging technologies that were developing, as well as the materials and the idea of providing these replacement bones just clicked. I saw that my little world of dental restorations was opening up to CAD/CAM. When the 3DP™ process came along the whole idea of a service to provide replacement parts just clicked.

Lau Christianson and Todd Jackson (3D Imaging) also selected the market in which to apply the 3DP™ process because of their prior knowledge of the market. However, in their case, the prior knowledge of the market appeared far shallower than was the case with the other entrepreneurs. Lau Christianson was a Sloan student who had worked in pharmo-economic and health care consulting prior to attending Sloan.

Mike Padnos' (Conferences) selection of a market also was influenced by prior knowledge of a market—in this case consumer retail goods. However, Mike's knowledge was developed from work *and* personal experience. Mike is in the art business and is a collector of sculpture. His house is full of folk art, primarily sculptures of human heads.

Identification of How to Serve the Market. As Table 6 shows, in all eight cases, the founders' prior knowledge also influenced the choice of how to serve the markets. Because Yehorem Uziel (Soligen) had previously founded a manufacturer of capital equipment and had extensive experience in machine design and manufacture at 3D Systems, he recognized the opportunity to embody the 3DP™ process in a machine rather than to provide a service.

Z Corp also discovered an opportunity to serve markets by selling a machine because of the prior knowledge of the entrepreneurs. Marina Hatsopoulos' (Z Corp) mechanical engineering background allowed her to recognize the opportunity for a tangible electromechanical physical product rather than a service; and Jim Bredt's (Z Corp) experience in machine design allowed the Z Corp team to recognize how to build low cost, office compatible machines that would serve the market in a better way than an alternative service bureau business model. Marina Hatsopoulos (Z Corp) explains:

> We envision the system as being placed right next to the designer in his office. The biggest advantage of using the 3DP™ process for concept models is the speed and you lose that advantage if you have to wait to get a file from a customer, give them a quote, get the file, do the backlog, print it out and send it out . . . . You know that if the big advantage is that you can print our part in an hour instead of ten hours, but you are going to take 24 hours to get them the part, then what's the point?

In contrast to the founders of Z Corp, the founders of 3D Partners were unable to recognize a way to manufacture machines because of their lack of knowledge in the area of machine design and manufacture. Andrew Kelly (3D Partners) explains:

> We could only discover the service market for architectural models. To think of how to make machines that do concept models, one would need a Ph.D. with expertise like Jim Bredt (Z Corp) . . . . I was a second year master's student in Mechanical Engineering at MIT and had a Bachelor's Degree in Mechanical Engineering from NC State. I could run a Z Corp machine, but I couldn't create one. To make machines, you would need to be familiar with things like infiltration kinetics. You would need to know what you are doing with materials, what's going on with powder and stuff like that. You would need to know these things in grand detail. I mean down to the details of how to capture droplets in space and infiltration time. The list goes on and on, down to surface chemistry and fluid handling, delivery systems, general machine design, and a long list of things that it takes to design a machine. These were not things I knew.

Consequently, the entrepreneurs who founded 3D Partners recognized an opportunity which they later believed to be inferior to the opportunity discovered by Z Corp.

Table 6 The Selection of How to Serve the Market

Company	Examples of Respondents' Descriptions of How to Serve the Market, Not Quoted in the Text
Therics	"MIT was working with one binder solution and one powder and neither was a polymer nor a polyester. Drugs require you to work with more than a single solution as well as with things like polymers and polyesters. My prior experience in pharmaceuticals made it clear to me that they could do the same thing with these materials. Also MIT had a bubble jet printer. I knew we had to change that. A bubble jet printer works by taking a liquid and making a bubble by heating it and spitting it out the other end. You can't go to the Food and Drug Administration and convince them that the liquid that went in is the same as the liquid that came out even though it went through a vapor phase. In addition, if it's a liquid that is heat labile, you're screwed."—Walter Flamenbaum
Specific Surface	"It would have been impossible for us to engineer machines for the 3DP™ process. We are not mechanical engineers like the people at Soligen. When we started Specific Surface Corporation we did not know how to make machines for the 3DP™ process."—Mark Parrish
	"The 3DP™ process seemed to answer a lot of the questions about what I was trying to do with other methods. I knew a fair bit about rapid prototyping because I'd been exposed to it where I used to work . . . . The 3DP™ process offers the possibility to eliminate a lot of manufacturing steps, down to really a handful of steps from design to finished product. With this process, I can tip ceramic material into a machine, download a design, and make a ceramic filter without any particular skill whatsoever. And that was what I saw as a really big advantage in making a functional product."—Andrew Jeffrey
Soligen	"There are very few people who can develop new equipment . . . [or] who are capable of combining so many engineering disciplines and ending up with a machine."—Yehorem Uziel
	"Their choice of this approach to serve the market was colored by their experience. They came from the manufacturing side of the business. They knew how to make machines."—Martin Omansky, a venture capitalist who evaluated Soligen.
3D Imaging	"[We] do not have any experience in the manufacturing of the machines themselves . . . . Someone else would have to make machines because we do not know how to do it . . . . "[One] reason to head in the direction of a service is because the piece of three-dimensional printing that Todd has been working on is the CAD interface program."—Lau Christianson
	"I understand how a machine to do this would work, but I could not sit down and build it . . . . [My research focuses on how] to represent smoothly varying compositions within the computer by assigning different materials or colors to the computer commands. Since this is very memory intensive you would want to make something that would create more value from this complexity. Information from medical file data is one example of that."—Todd Jackson
Conferences	"I'm a lawyer, but I know consumer businesses. I have no more technology affinity than I have the ability to walk on the moon . . . . I can't do science or math at all. I could only see how this could come together with consumer stuff in an nontechnology way. I didn't want to sell a computer or something where I had to know where a C drive was."—Mike Padnos

Like founders of 3D Partners, the founders of 3D Imaging also discovered a service to exploit the 3DP™ process because they could not manufacture machines. However, unlike 3D Partners, 3D Imaging's entrepreneurs also had prior of knowledge of technology that would generate greater value in the form of a service than in the form of a machine. By exploiting a piece of complex computer software, 3D Imaging could make direct use of Todd's Ph.D. dissertation research on the processing of composition information into machine instructions.

Andrew Jeffery and Mark Parrish (Specific Surface) were similar to the founders of 3D Imaging in the influence of their prior knowledge on their discovery of how to serve the market. Andrew Jeffery explains that their lack of knowledge about machine design led them not to discover an opportunity to manufacture machines, but to make filters using a modified Soligen machine.

Specific Surface's discovery of how to serve the market was also influenced by another dimension of prior knowledge not present with any of the other entrepreneurs. Specific Surface Corporation uses the 3DP™ process to manufacture a final product through a one-stop manufacturing process. Andrew saw the 3DP™ process as "a true manufacturing process right from the start" because he had

been looking at rapid prototyping as a way to reduce the number of steps in the labor intensive process of making filters in his previous product development job.

Similar to the other sets of entrepreneurs, Walter Flamenbaum's (Therics) prior knowledge influenced how Therics would serve the market. Unlike the cases of the other entrepreneurs, however, the important prior knowledge in Walter's case was an understanding of how one serves a market that depends on government approval. Because of his pharmaceutical experience, Walter recognized what materials could be substituted to make drugs in place of the powders MIT was using and how to change the MIT machine into one that would get FDA approval.

Like the other entrepreneurs, Stephen Campbell (3D Orthopedics) recognized a way to serve the market because of his prior work experience. However, unlike the other entrepreneurs, Stephen recognized how to make custom-fitted replacement bones from information scanned from an MRI because his prior work experience allowed him bring together the 3DP™ process and other new technologies to which he was exposed.

Finally, Conference's discovery of how to serve the market was also influenced by Mike Padnos' (Conferences) prior knowledge. Mike explained that Conferences would establish retail establishments in malls because his prior background in service businesses and personal experience led him to understand how to serve retail customers.

Identifying a Solution to the Customer's Problem. Table 7 shows that, in all eight cases, prior knowledge led the entrepreneurs to see the usefulness of the 3DP™ process in solving different customer problems. The prior work experience of Z Corp's entrepreneurs allowed them to see the 3DP™ process as a solution to the customer problems of speed and cost. Because Jim Bredt's (Z Corp) research often led him to use cannibalized computers and printers scavenged from junk piles, he recognized the value of modifying a standard ink jet print head to lower costs. Similarly, his education in materials science at MIT led him to notice that one could use inexpensive starches as the powder for the system in place of more expensive materials.

In contrast, Yehorem Uziel's (Soligen) prior experience as an inventor of a rival technology led him to recognize the usefulness of the 3DP™ Process to solving a set of customer problems that could not be solved by the alternative of stereolithography. He explains:

> In the future there will be no need for prototypes or mock-ups because everything will be done in cyberspace . . . . One day you'll be able to supplant most of the trial and error in engineering design with computer simulation. Moreover, rapid prototyping uses exotic fabrication processes that will never become production methods. For example, there is no way that anyone will be able to drive a laser as fast as needed to create something that will compete with the injection mold piece. So rapid prototyping can never yield functional parts. Even if you solidify a liquid which is exactly nylon, this is not the same properties of nylon which is injection molding. The only way to really address the concept of building parts from CAD is to do something intermediary like make an expendable mold. [Moreover,] plastic patterns are not durable enough and have long-term dimensional instability (they may warp or distort as time goes by and internal stresses are relieved.) For investment casting, plastic patterns do not dissolve easily and may crack the shells, and wax patterns made by laser sintering—which involves joining wax powder particles into a wax object using a laser beam—do not have the required accuracy and surface finish. (Uziel, 1993: 3)

Andrew Jeffrey's (Specific Surface) prior knowledge in product development at a filter manufacturer allowed Specific Surface to recognize trends toward hot filtering and smaller sized filters in power plants. In addition, Mark Parrish's (Specific Surface) Ph.D. and extensive work experience in ceramic engineering allowed him to recognize the usefulness of the 3DP™ process in solving a customer problem in *different ceramics* from those with which MIT researchers had been working.

Like the other entrepreneurs, Walter Flamenbaum's (Therics) prior knowledge led him to recognize the value of the 3DP™ process to solving a customer's problem. Because Walter had 25 years of experience in clinical pharmacology and a research interest in cronopharmacology, he recognized how the 3DP™ process would solve a problem with the treatment of hypertension.

Brad Vale, a venture capitalist at Johnson and Johnson Development Corporation that funded Therics, explained why Walter Flamenbaum's background led to the discovery of different solutions to customer problems than those discovered by other entrepreneurs. He explains:

> People always have a handful of unsolved medical industry problems floating in the back of their heads. One of them is artificial bone. People coming from that background went down a particular path. On the other hand, people from a drug background start thinking what is the huge value added. That would be complex drug delivery. They have the problem of drug delivery that matches up with daily cycles in the back of their minds. This sends them down a different path from the medical device people.

Unlike the other entrepreneurs, Stephen Campbell's (3D Orthopedics) recognition of a solution to a customer problem came from a combination of research, experience as a user, and prior education. At the time he learned

Table 7 The Solution to the Customer's Problem

Company	Example of Respondents' Descriptions of the Solution to the Customer's Problem, Not Quoted in the Text
Z Corp	"Most of the people who looked at the technology were coming to it with a pretty specific need that was not quick and dirty printing. Most of them wanted extreme accuracy and looked at three-dimensional printing from that point of view. We saw . . . a quick and dirty way, almost a sloppy way to do what MIT was trying to do."—Walter Bornhorst
Therics	"There was a lot of evidence indicating that we were not appropriately treating high blood pressure because we weren't appropriately taking into consideration the variations in blood pressure during the course of the day . . . . Even when we give people drugs, there continues to be arterial sclerotic cardiovascular disease . . . because we don't hit a morning rapid change in the rate of rise in blood pressure. If you can control the amount and time of drug release to changes in blood pressure over a person's daily cycle, you can solve [these] problems . . . . If you are a clinical pharmacologist . . . you look at something that you can control with microarchitecture and materials. I had this 'chronopharmacological logic,' and intuitively looked at the technology and thought we could use it to compartmentalize the release of drugs . . . . If you know this, seeing three-dimensional printing as a way to make time release drugs is quite reasonable, intuitive reasoning."—Walter Flamenbaum
Specific Surface	". . . the 3DP™ process can make uniform porosity ceramics, which is an incredibly difficult thing to do . . . . I knew about materials that were different than those that Ely and his people were using in the lab [and that] made it possible to see how to make ceramic filters."—Mark Parrish
	"There were two things that were happening. One, people didn't want to cool down gasses to filter them, everyone wanted to filter hot at the source. Two, people want more compact filters . . . . To do that, you have to get more surface area in the same volume or the same surface area in a smaller volume of filter. A trend was emerging . . . with the rise of cartridge filter people getting into the industrial area. The same thing had started to happen in hot gas filtration and . . . I saw [that] the real benefit . . . was being able to get a lot of surface into a smaller filter."—Andrew Jeffrey
3D Partners	"From experience, he knew that the architectural model making industry . . . hasn't changed a lot from exacto knives, mylar, and foam. It is very time-intensive and takes a lot of crafts experience. By . . . setting up a service bureau to use 3DP™, you could get around that problem."—Andrew Kelly.
3D Orthopedics	"As a medical professional I was also aware of the shortcomings of existing surgical techniques. They're using cadaver bones . . . or they're using pre-formed things that are either plastic or ceramic. The surgeon is literally hand grinding a big block of material during surgery . . . . They don't fit well and controlling and restoring normal form and contours is difficult, if not impossible . . . . The 3DP™ process would allow you to provide an anatomically accurate form that fit the defect so that it restored the area to normal contours. This avoids problems that affect patients aesthetically and even functionally . . . . There were a few start-up companies involved in laser lithography. This allowed three-dimensional forming of some polymer-based materials. This was very limiting because if you are going to make replacement body parts, you have to be able to use all materials . . . . One thing that the 3DP™ process did is to allow you to use the whole world of materials . . . . I was doing a lot of research in ceramics and I have an advanced degree in materials science. I also do work on replacement teeth and bones. I know that there are certain microstructures that are conducive to being replaced by bone. Biological applications require that you control the microstructure and macrostructural aspects, and the 3DP™ process lets you do that . . . . I thought that the 3DP™ process would allow us to make a scaffold matrix which would allow for the in growth and replacements with the patient's own bone . . . ."—Stephen Campbell
3D Imaging	"I knew that the 3DP™ process could solve this problem and that stereolithography could not because of my technical background. It was clear from that work that sterolithography could only print in two colors, but the 3DP™ process could print in many."—Todd Jackson
Conferences	"I knew that people like images of themselves and their families, but they would prefer them in three dimensions. They would like little busts of themselves and their families, rather than just photos of them."

of the 3DP™ process, Stephen was working on a program at Brigham and Women's hospital to reconstruct images from MRIs and CAT scans to construct 3-D models of bones. His prior education in materials science allowed him to understand how the 3DP™ process would solve the problem of creating artificial body parts in multiple

materials; whereas his surgical experience led him to recognize how the 3DP™ process would make surgery to replace body parts easier and more effective.

Prior knowledge also influenced Lau Christianson (3D Imaging) and Todd Jackson's (3D Imaging) discovery of a solution to particular customer problems. However, unlike many of the entrepreneurs, Lau and Todd recognized this solution because of prior knowledge about technology. Todd Jackson knew how to use three-dimensional printing to make objects out of multiple materials and in multiple colors because he is pursuing a Ph.D. at MIT, where he is designing a CAD interface program that ''will take the image as constructed on the computer and allow the 3D printer to put different materials next to each other. This is the equivalent of color printing. You can go ahead and put multiple materials together or two different colors together.'' He explains that the customer problem that 3D Imaging would solve is exactly the problem that he was trying to solve in his thesis.

Mike Padnos' (Conferences) solution to a customer problem also was influenced by his prior knowledge. However, unlike the other entrepreneurs, who developed this solution through prior work experience or education, Mike developed his prior knowledge as a consumer. He recognized that people go to malls to buy photographs of themselves and their families so he decided to start a business in which he would make three-dimensional sculptures from photographs.

In contrast, 3D Partners recognized how to use the 3DP™ process to solve a customer problem because of the founders' prior knowledge as users. 3DP Partners would solve the problems of speed and cost in architectural model making by allowing less experienced and less costly employees to produce models in one-tenth of the time that they currently take. The team recognized the solution to the customer problem of speed and cost because the architect on the team knew from prior experience how time consuming and skill-intensive the craft of producing concept models was.

Discussion

Existing explanations for entrepreneurship are incomplete because they do not explain adequately the process of opportunity discovery, an important part of the entrepreneurship process (Kirzner 1997). This study proposed that all people are not equally likely to recognize the same entrepreneurial opportunities which result from technological change. It also proposed the entrepreneurs can and will discover opportunities through recognition rather than search. Moreover, it proposed that the prior distribution of knowledge in society influences who discovers these opportunities.

Limitations

This article is not without limitations. First, although the study provides direct evidence that individuals will discover opportunities related to their prior knowledge, it provides only indirect evidence about the ability of some people and not others to discover opportunities. Second, the sample is composed of highly educated people who might have been trained to discover opportunities. Consequently, the results might not generalize to the overall population. Third, the respondents provided self-reported data, based on introspection and retrospection. They might have rationalized a process that had either favorable or unfavorable outcomes for them. Fourth, the study examined only entrepreneurs. Therefore, the results might be subject to selection effects that would not be present if nonentrepreneurs had been included. Nevertheless, the strength of the results and their importance to entrepreneurship theory suggests that future researchers consider the role of prior knowledge in the discovery of opportunity.

Contribution to Research

The results have several important implications for entrepreneurship theory. Prior research makes several assumptions that are inconsistent with the empirical results found here. Technological change does not generate obvious entrepreneurial opportunities, which allow anyone to discover any given entrepreneurial opportunity which results from that change. Cognitive limits and the specialization of knowledge preclude entrepreneurs from identifying the complete set of entrepreneurial opportunities in a given technology and comparing between alternatives to select the best one in which to invest (Aldrich and Zimmer 1986). Moreover, the results show that the process of discovery can be driven by recognition of knowledge already possessed rather than by search for knowledge needed (Kirzner 1997). Consequently, individuals who have developed particular knowledge through education and work experience will be more likely than other people to discover particular entrepreneurial opportunities in response to a given technological change (Venkataraman 1997).

The results also provide evidence that individual differences influence the discovery of opportunities in a different way than that generally described in the literature. This study suggests that entrepreneurs discover opportunities, not because they have special attributes (e.g., unusual perceptive ability) that make them better able to recognize opportunities (Schumpeter 1934, p. 79; Shackle

1982), but because idiosyncratic prior knowledge makes people better able to discover certain opportunities than others (Venkatarman 1997, Fiet 1996). This finding is important for two reasons. First, it provides a role for individual-level attributes that may be more likely to generate large, statistically significant, robust, and consistent differences across samples than do explanations that depend on the superiority of entrepreneurs on some dimension.

Second, the results reiterate the importance of individual differences to the entrepreneurship process, and demonstrate that entrepreneurship can not be explained solely by reference to factors external to individuals, like competition or prior firm foundings (e.g., Singh and Lumsden 1990). In fact, the results suggest that individual differences may imprint the development of new organizations even before they are founded. This is important because previous research has shown only that new organizations are programmed during firm infancy not before birth (Stinchombe 1965).

The findings also have important implications for theories of economic growth. While Rosenberg (1994) and others have provided numerous historical examples in which inventors failed to recognize the commercial value of their inventions, ranging from the telephone to the laser, theories of economic growth typically ignore the question of opportunity discovery in the process of technological change. These theories generally assume that the development of new technology leads to an immediate increase in economic output because entrepreneurs immediately *grasp* the entrepreneurial opportunities that result from technological change (Kirzner 1985). This study shows that before technological change can influence output, an individual must perceive an entrepreneurial opportunity. Because not all entrepreneurs will perceive the same opportunities, some desirable entrepreneurial opportunities may go unnoticed and unexploited.

Moreover, a small amount of technological change might generate a large amount of economic output because entrepreneurs discover a large number of opportunities in which to exploit the technology. Conversely, a large amount of technological change might generate a small amount of economic output because it generates a small number of entrepreneurial opportunities. Furthermore, ''at any given point in time output may be less than is possible and desired, because of opportunities that have remained unnoticed'' (Kirzner 1985, p. 74–75).

Future Directions

This study also suggests several avenues for future research. Scholars could examine how prior knowledge influences opportunity discovery outside of the context of high technology. For example, would two potential entrepreneurs, one with a restaurant background and the other with an apparel background, look at the same vacant storefront and see restaurant and clothing store opportunities, respectively? While the results of this study would suggest an affirmative answer, prior knowledge might interact with the complexity of discovering the opportunity. Therefore, investigation of how prior knowledge influences the discovery of opportunities across different business settings would be valuable. Possible approaches to researching this question include field studies of entrepreneurs who rent the same retail space, experimental studies designed to manipulate the information about opportunities, or longitudinal observation of particular retail locations.

In addition, the results suggest that future research on the exploitation of opportunities should control for variation in the attributes of the opportunities that different entrepreneurs discover. Previous research has drawn conclusions about the effect of individual differences on the decision to exploit entrepreneurial opportunity based on the assumption of a zero correlation between individual differences and opportunity discovery (Khilstrom and Laffont 1979, Evans and Jovanovic 1989). Because individual differences influence the discovery of opportunity *and* the decision to exploit opportunity (Schumpeter 1934, p. 79), this assumption has led to results that overstate the effects of individual differences. The lack of controls for the value of opportunities has led researchers to falsely attribute the variance belonging to the opportunity to the individuals. To accurately explain the role of individual differences in the tendency to exploit opportunities, researchers must examine the variance in the individuals net of the variance in the opportunities that they discover. This could be done several ways. Cross-sectional studies could include measures of the attributes of the entrepreneurial opportunity as control variables in a regression equation. Alternatively, longitudinal studies could measure multiple opportunities for the same individual to partial out the portion of the decision influenced by the opportunity.

Normative Implications

The finding that the discovery of entrepreneurial opportunities depends on prior knowledge has several implications for individuals seeking to become entrepreneurs. People will be more likely to discover opportunities in sectors that they know well than in sectors that are ''hot,'' because the investment in the information necessary to recognize opportunities is likely to occur long before a

particular sector is popular. Therefore, potential entrepreneurs should look to discover opportunities in what they know rather than in what is popular with other entrepreneurs.

In addition, opportunity evaluation involves a comparison between the discovered opportunity and other alternatives to entrepreneurship that the entrepreneur faces, rather than between the value of the discovered opportunity and other entrepreneurial opportunities that the entrepreneur is unlikely to identify. Consequently, evaluation of opportunity involves comparing opportunities to one's own opportunity cost and liquidity and uncertainty premiums, not comparing one's own opportunity to those of other entrepreneurs.

Furthermore, the effect of prior knowledge on opportunity discovery also creates interesting wrinkles in the relationship between entrepreneurs and investors. To raise money, entrepreneurs have to disclose their opportunities to potential investors. If investors are approached by multiple entrepreneurs who have identified different opportunities to exploit a given technology, the investors may learn about the existence of more opportunities than any given entrepreneur recognizes. They may choose not to fund an entrepreneur's opportunity because other entrepreneurs proposed better ways to exploit the same technology. This structural difference in information suggests that entrepreneurs should obtain control over the rights to exploit new technology to improve their probability of receiving funding. The patent system allows an entrepreneur to prevent future entrepreneurs from exploiting a given technology even if the future entrepreneur discovers a more valuable use for the technology than the first entrepreneur.

The field evidence provides at least one example of this process. Subsequent to Walter Flamenbaum's discovery of the opportunity to use the 3DP™ process to make drugs, Lau Christianson and Todd Jackson discovered the opportunity to use the 3DP™ process to make surgical models. Even if Lau and Todd's opportunity were more valuable than Walter's, Therics had already obtained from MIT the rights to all medical applications for the 3DP™ process. Therefore, Therics was protected against investor preference for Lau and Todd's application for the 3DP™ process.

The results also provide several implications for public policy. Government policies to promote entrepreneurship generally provide disproportionate funding to disadvantaged groups to enhance the probability that people in these groups will become entrepreneurs. However, if the discovery of entrepreneurial opportunities is dependent upon prior knowledge, disadvantaged groups might fail to become entrepreneurs not because they lack the resources to do so but because they lack the prior knowledge necessary to discover valuable opportunities. Consequently, a public policy solution to lack of entrepreneurship among certain groups may be to invest in the development of knowledge in these disadvantaged groups.

In addition, the findings suggest that unrecognized costs to society are incurred where patent holders grant world-wide exclusive licenses to their discoveries. By granting an exclusive license, a patent holder precludes the possibility that a future entrepreneur will exploit a more valuable use for the technology than the one proposed by the exclusive licensee. While this cost of exclusive licensing might prove smaller than the benefits that exclusivity provides, to date public policy has treated this cost as nonexistent. Future research would greatly inform public policy if it weighed the costs and benefits of world-wide exclusivity to technical discoveries.

Finally, the results show that efforts to centralize opportunity discovery will meet with difficulty. Some researchers have argued that a decentralized economy will have difficulty in fully exploiting the growth returns of general purpose technologies. Exploitation by multiple entrepreneurs in different fields creates duplication of effort, reduces the economies of scale and scope from coordination, and creates contracting problems (Bresnahan and Trajtenberg 1995). However, decentralization has offsetting advantages in the discovery of opportunities. Nelson (1987) argues that uncertainty combined with differences in knowledge among experts makes the efforts to plan and coordinate the development of new technology ineffective. Central agents, such as university technology licensing officers or government officials will be unable to identify all of the entrepreneurial opportunities to exploit a given new technology because they have prior knowledge about some markets and technical fields, but not others. Consequently, as Hayek (1945) argued, governments and organizations cannot successfully centralize the process of opportunity exploitation.

Conclusion

This paper showed that differences in prior information influence who discovers entrepreneurial opportunities to exploit new technology. This finding generates several important implications for development of theory, public policy, and the practice of entrepreneurship. Hopefully, future researchers will use the concepts of limited information and entrepreneurial discovery presented here to generate a robust explanation for entrepreneurship.

Acknowledgments

The author thanks Ajay Agrawal, Pierre Azoulay, Terry Blum, Paul Carlile, Shane Greenstein, Josh Lerner, Richard Nelson, Holly Raider, Ed Roberts, Sheena Sethi, Scott Stern, and the participants in the Emerging Technology seminar series at Wharton, the Management of Technology seminar series at MIT, the Austrian Economics Seminar at NYU, the Summer Institute for Spanish Management Scholars at Harvard University, and in seminars at the Darden School and the University of North Carolina for their helpful comments on an earlier draft of this paper.

Endnotes

[1]To my knowledge, no prior research has examined the effect of prior experience, training, or education on the discovery of opportunities.

[2]Under this definition, entrepreneurs are people who have engaged in behavior to discover, evaluate, and exploit opportunities, even if they have engaged in only one stage of the entrepreneurial process.

[3]On December 8, 1989, MIT filed for a patent on this technology in the United States and Europe, which was issued on April 20,1993 (patent number 5,204,055). MIT also filed for patents in Canada and Europe on December 5, 1990, and in Japan on December 10, 1990. The Canadian patent issued on November 22, 1994, and the European patent issued on May 24, 1995.

References

Aldrich, H., G. Wiedenmayer. 1993. From traits to rates: An ecological perspective on organizational foundings. In *Advances in Entrepreneurship, Firm Emergence, and Growth*, Vol 1. J. Katz, ed. JAI Press, Greenwich, CT.

——, and C. Zimmer. 1986. Entrepreneurship through social networks. In *The Art and Science of Entrepreneurship*. D. Sexton and R. Smilor, eds. Ballinger, Cambridge, MA.

Baron, R. Counterfactual thinking and venture formation: the potential effects of thinking about ''what might have been.'' *J. Bus. Venturing*. Forthcoming.

Begley, T., D. Boyd. 1987. Psychological characteristics associated with performance in entrepreneurial firms and smaller businesses. *J. Bus. Venturing* **2** 79–93.

Boeker, W. 1988. Organizational origins: entrepreneurial and environmental imprinting at the time of founding. In *Ecological Models of Organizations.* G. Carroll, ed. Ballinger, Cambridge, MA.

Bresnahan, T., Trajtenberg. 1995. General purpose technologies 'engines of growth'? *J. Econometrics* **65** 83–108.

Brockhaus, R., P. Horowitz. 1986. The psychology of the entrepreneur. In *The Art and Science of Entrepreneurship*. D. Sexton and R. Smilor eds. Ballinger, Cambridge, MA.

Busenitz, L., J. Barney. 1997. Differences between entrepreneurs and managers in large organizations: Biases and heuristics in strategic decision-making. *J. Business Venturing* **12** 9–30.

Carroll, G., E. Mosakowski. 1987. The career dynamics of self-employment. *Admin. Sci. Quart.* **32** 570–589.

Casson, M. 1982. *The Entrepreneur*. Barnes and Noble Books, Totowa, NJ.

Chen, C., P. Greene, A. Crick. 1998. Does entrepreneurial self-efficacy distinguish entrepreneurs from managers? *J. Bus. Venturing* **13**(4) 295–316.

Cohen, W., D. Levinthal. 1990. Absorptive capacity: A new perspective on learning and innovation. *Admin. Sci. Quart.* **35** 128–152.

Evans, D., B. Jovanovic. 1989. An estimated model of entrepreneurial choice under liquidity constraints. *J. Polit. Econom.* **97**(4) 808–827.

Fiet, J. 1996. The informational basis of entrepreneurial discovery. *Small Bus. Econom.* **8** 419–430.

Hayek, F. 1945. The use of knowledge in society. *Amer. Econom. Rev.* **35**(4) 519–530.

Kaish, S., B. Gilad. 1991. Characteristics of opportunities search of entrepreneurs versus executives: Sources, interests, and general alertness. *J. Bus. Venturing* **6** 45–61.

Khilstrom, R., J. Laffont. 1979. A general equilibrium entrepreneurial theory of firm formation based on risk aversion. *J. Polit. Econom.* **87**(4) 719–748.

Kirzner, I. 1973. *Competition and Entrepreneurship*. University of Chicago Press, Chicago, IL.

——. 1985. *Discovery and the Capitalist Process*. University of Chicago Press, Chicago, IL.

——. 1997. Entrepreneurial discovery and the competitive market process: An Austrian approach. *J. Econom. Lit.* **35** 60–85.

McClelland, D. 1961. *The Achieving Society.* D. Van Nostrand, Princeton, NJ.

Miles, M., A. Huberman. 1984. *Analyzing Qualitative Data: A Sourcebook for New Methods*. Sage, Beverly Hills, CA.

Nelson, R. 1987. Capitalism as an engine of progress. Working Paper, Columbia University, New York.

——, S. Winter. 1982. *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

Roberts, E. 1991. *Entrepreneurs in High Technology: Lessons from MIT and Beyond*. Oxford University Press, New York.

Rosenberg, N. 1994. Uncertainty and technological change. *Conference on Growth and Development: The Economics of the 21st Century.* Center for Economic Policy Research, Stanford University.

Schumpeter, J. 1934. *Theory of Economic Development*. Harvard University Press, Cambridge, MA.

Shackle, G. 1982. *Imagination and the Nature of Choice.* Edinburgh University Press, Edinburgh, Scotland.

Shane, S., S. Venkataraman. 2000. The promise of entrepreneruship as a field of research. *Academy of Management Review.* **25**(1) 217–226.

Shaver, K. G., L. R. Scott. 1991. Person, process, and choice: the psychology of new venture creation. *Entrepreneurship Theory and Practice.* Winter 23–42.

Singh, J., C. Lumsden. 1990. Theory and research in organizational ecology. *Ann. Review Sociology* **16** 161–195.

Stigler, G. 1961. The economics of information. *J. Political Econ.* **69**(3) 213–225.

Stiglitz, J. 1994. *Whither Socialism?* MIT Press, Cambridge, MA.

Stinchcombe, A. 1965. Social structure and organizations. In *Handbook of Organizations.* J. March, ed., Rand McNally, Chicago, IL.

Uziel, Y. 1993. Functional prototyping—has the future arrived? *Foundry* (March) 1–5.

Venkatarman, S. 1997. The distinctive domain of entrepreneurship research: an editor's perspective. In *Advances in Entrepreneurship, Firm Emergence, and Growth*. J. Katz, R. Brockhaus, eds. JAI Press, Greenwich, CT.

Von Hippel, E. 1988. *The Sources of Innovation.* Oxford University Press, New York.

——. 1994. ''Sticky information'' and the locus of problem solving: implications for innovation. *Management Sci.* **40**(4) 429–439.

Yin, R. 1984. *Case Study Research: Design and Methods.* Sage, Beverly Hills, CA.

Accepted by Alan Meyer; received July 1998. This paper has been with the author for two revisions.