

Radical Innovation

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Abstract.

What is radical innovation and how has radical innovations literature been reflected over time? There is a surprising dearth of literature examining radical innovations, yet, a common definition in either quantitative or qualitative terms has yet to emerge. This paper reviews the radical innovation literature and suggests the potentially missing area of research, namely the Knowledge Filter. The paper furthermore offers a set of measure indicators to determine the extent of radical innovation, in both *ex ante* and *ex post* analysis using the Dahlin-Behrens model of radical identification as a means to identify radical innovations.

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“Two types of inventive effort are not as inherently substitute activities as they may appear to be. Rather, there has been a predictable tendency toward specialization, with the entrepreneurs providing the more heterodox, breakthrough innovations, and the

R&D establishments of the larger firms creating the enhancements to those breakthroughs that contribute considerably to their usefulness. These “Goliath” innovators have not eliminated the role of the entrepreneurial “Davids.” Instead, the two have tended to specialize and, together, they have enhanced the process beyond what either type of innovator might have been able to achieve by itself.”

William Baumol, P.28

1. Introduction

Since the 1970s the concept of radical innovation in economic theory as a driving force of economic growth. Yet, the term itself offers a plethora of concepts and definitions which can be vexing to policy makers and scholars hoping to identify *ex ante* radical innovations to expedite and facilitate growth. Building a universal and compelling concept and methodology identifying radical innovation remains elusive and problematic for scholars for several reasons. First, terminology of the definition has varied from: really new, to breakthrough innovation, discontinuous, generational and finally radical innovation. The differing etymology is, in part, due to the differing fields of research that study radical innovation. The differing terms each carry the spirit of what radical innovation creates, yet are unable to provide a unifying foundation for distinguishing radical innovation.

Second, which represents an even more troublesome problem, is the difficulty to quantify or recognize what actually constitutes a radical innovation *ex ante*. This problem is the famous “I know it when I see it” issue. Traditionally, policy makers and scholars are unable to identify nascent radical innovations *ex ante*. For example, how many policy makers were able to identify the radical innovations and consequent economic growth that Microsoft, the digital camera, or

Google delivered to economies? Given the difficulty of identifying these innovations *ex ante*, how can one aggregate radical innovations' contribution to economic growth for a region or country? For this reason, most scholars leave the definition abstract and instead have focused their research on the concept and the *ex post* impact of singular fields of radical innovative activity.

The interim report will define innovation and give a brief description and distinction between radical innovation and incremental innovative activity in the second section. The third section applies the Dahlin and Behrens (2005) heterogeneous classifications of radical innovations in the literature. The classifications identify the differing forms radical innovation is engendered in the literature. The fourth section offers conclusions and suggestions to identify radical innovations *ex ante* in a uniform manner..

2. Origins of Radical Innovation

The concept of innovation, at least implicitly, dates back at least to Joseph Schumpeter's seminal 1934 treatise, *Theory of Economic Development; and Inquiry into Profits, Capital, Credit, Interest and the Business*. His term, the "process of creative destruction", conceptually and literally began a radical revolution in economic theory and commercial orientation. Indeed, the process as Schumpeter argued, was one where large firms were destroyed by the entrepreneur who seizes commercial opportunities from inventors. Entrepreneurs enter the market with such commercial competitive advantages due to their potential

innovations that they can not only compete, but “destroy” incumbent firms and their respective economies to scale due to the entrepreneur’s superior innovation. Schumpeter’s work on creative destruction creates the foundation for innovation.

As McCraw (2007) points out, at the center of Schumpeter’s intellectual contribution was a focus on innovation. Schumpeter, more than any of the great economists before him, viewed innovation as the driving force of progress and development. But Schumpeter also emphasized that innovation, and therefore economic progress, comes at a price – creative destruction. Just as the factory wiped out the blacksmith shop and the car superseded the horse and buggy, incumbents will be displaced by innovating entrepreneurs. As McCraw (2007, p. 6) concludes, “He knew that creative destruction fosters economic growth but also that it undercuts cherished human values. He saw that poverty brings misery but also that prosperity cannot assure peace of mind.”

However, Schumpeter did not distinguish explicitly between radical innovation and other types of innovative activity. While one may infer that Schumpeter’s creative destruction replaces old technologies and expands new commercial opportunities, the concept of radical innovation must refer to a much more specific type of innovation which is traditionally identified in *ex post* analysis.

Along with Schumpeter, many other scholars applied *ex post* identification of radical innovations for their empirical investigation. This method, however, creates several problems for both scholars as well as policy makers. As will be shown below in more detail, the *ex post* identification causes two problems. First in a practical and pragmatic sense, one would ideally wish to identify an emerging

radical innovation in an early and incipient stage in order to expedite commercial entry into the market. Secondly and more importantly, the studies based on *ex post* analysis have inherent methodological problems. According to Dahlin and Behrens (2005, p.718), “basing identification of radical inventions on market success by only including innovations in a study, for instance, ignoring inventions that never reach the market, creates a selection bias; indeed, technologies might be radical in a technological sense without having significant market impact, since the market impact of a technology is affected by many non-technological conditions.”

2.1 Descriptive Sources of Firm Size and Radical Innovations

“What Skype is doing is like a toy. They will realize they can’t scale it, they don’t have a brand like the AT&T brand, and they don’t have the local footprint, which we have. It’s going to be very hard to compete with someone like AT&T.”

Source: Hossein Eslambolchi, AT&T’s CTO and president of AT&T labs. As quoted from Rao et al. P. 182

First, in order to understand where radical innovations originate from, we will offer a brief descriptive summary on who has delivered radical innovations. To better understand how heterogeneous the sources are of radical innovations. We will offer a quick exercise in some exemplary list of where radical innovations originate from.

We offer three areas of where radical innovations originate from small firms and Large Firms

Small Firm Entrepreneurship

As one can clearly see from Table 1, taken from Baumol's 2004 working paper in NBER, the example list radical innovations delivered by small firm entrepreneurs up until 1995 is highly substantial. Since 1995, multiple new pistons of economies have emerge. Some pistons are for example, information technology (e.g. Microsoft, Dell, Skype, or Ebay), and Renewable Resource technology (hybrid motor, wind technology), have since been placed on the impressive list. While there is no empirical investigation of how the radical technologies were developed, one can *ex post* immediately appreciate their value added to economies.

Table 1 Example List of Radical Innovations from Small Firm Entrepreneurs

Air Conditioning	Heart Valve	Prestressed Concrete
Air Passenger Service	Heat Sensor	Prefabricated Housing
Airplane	Helicopter	Pressure Sensitive Tape
Articulated Tractor Chassis	High Resolution CAT Scanner	Programmable Computer
Cellophane Artificial Skin	High Resolution Digital X-Ray	Quick-Frozen Food
Assembly Line	High Resolution X-Ray Microscope	Reading Machine
Audio Tape Recorder	Human Growth Hormone	Rotary Oil Drilling Bit
Bakelite	Hydraulic Brake	Safety Razor
Biomagnetic Imaging	Integrated Circuit	Six-Axis Robot Arm
Biosynthetic Insulin	Kidney Stone Laser	Soft Contact Lens
Catalytic Petroleum Cracking	Large Computer	Solid Fuel Rocket Engine
Computerized Blood Pressure Controller	Link Trainer	Stereoscopic Map Scanner
Continuous Casting	Microprocessor	Strain Gauge
Cotton Picker	Nuclear Magnetic Resonance Scanner	Strobe Lights
Defibrillator	Optical Scanner	Supercomputer
DNA Fingerprinting	Oral Contraceptives	Two-Armed Mobile Robot
Double-Knit Fabric	Outboard Engine	Vacuum Tube

Electronic Spreadsheet	Overnight National Delivery	Variable Output Transformer
Freewing Aircraft	Pacemaker	Vascular Lesion Laser
FM Radio	Personal Computer	Xerography
Front-End Loader	Photo Typesetting	X-Ray Telescope
Geodesic Dome	Polaroid Camera	Zipper
Gyrocompass	Portable Computer	Blackerry

Source: Baumol (2004)

Large Firm Innovation

Yet, the origins of radical innovations are more complex than the tradition belief of inventors in a garage coming up with a new idea. There are many cases where large and successful corporation have indeed, developed, implemented and profited from inhouse radical innovations For example, Nokia and the cell phone, Kodak and the digital camera, Apple Computers and the Iphone). Indeed, as Chandy and Tellis show in Table 2, there is a large field of radical innovation where large firms have invented and delivered product to the market.

Table 2 Example List of Radical Innovations From Large Firms:

AM radio	Wireless Telegraph and Signal Co.
Analog answering machine	American Telegraphone Co.
Analog quartz watch	Seiko
Black-and-white celluloid roll camera	Eastman Dry Plate & Film Co.
Camcorder	Sony
Cassette tape player	Phillips
Compact disc player	Phillips and Sony
Cellular telephone	Motorola
Digital answering machine	Sharp
Digital camera	Sony
Digital high-definition television	Panasonic
Digital video disc (DVD) player	Toshiba
Disposable shaver	Bic Corp.
Electric blanket	General Electric
Electronic Color Teleision	RCA
Electronic desktop calculator	Sharp
Laptop Computer	Tandy Corp. (Radioshack)

Laser disk player	Phillips
Laser Printer	IBM
Microwave	Raytheon
Mini-disc player	Sony
Palm computer	Amstrad

Source: Chandy and Tellis (2000)

2.2 Characteristics of Radical Innovation vis-à-vis Incremental Innovation

Dahlin and Behrens (2005) explicitly link the extent to which an *invention* is radical in terms of the nature of the ideas upon which the innovative activity is based, and in particular the extent to which the innovative activity involves information which is codified, or knowledge, which is inherently tacit in nature. Information refers to facts that can be codified and where the valuation across different agents, or employees and layers of decision-making bureaucracy within the organization is relatively constant. Innovative activity based on economic information tends to be incremental in nature, in that it generally involves an organizational consensus about the potential value and impact of the innovation. Thus, incremental innovation tends to be supportive and enhancing of the status quo organization.

By contrast, radical innovation is based on knowledge involving tacit ideas that not only defy codification, but also whose economic value remains highly uncertain and asymmetric and tends to generate radical innovations. The expected

value of any new idea is highly uncertain, and has a much greater variance than would be associated with innovative activity based on information.. When it comes to radical innovation, there is uncertainty about whether the new product or service can be produced, how it can be produced, and whether sufficient demand for that visualized new product or service might actually materialize (Arrow, 1962).

In addition, new ideas constituting tacit knowledge are typically associated with considerable asymmetries. For example, in order to evaluate a proposed new idea concerning a new biotechnology product, the decision maker might not only need to have a Ph.D in biotechnology, but also a specialization in the exact scientific area. Differences in education, background and experience can result in divergences in the expected value of a new project or the variance in outcomes anticipated from pursuing that new idea, both of which can lead to divergences in the recognition and evaluation of opportunities between economic agents and decision-making hierarchies. Such divergences in the valuation of new ideas will become even greater if the new idea is not consistent with the core competence and technological trajectory of the incumbent firm. Thus, radical innovation tends to be disruptive to the status quo firm organization and strategy.

In fact, what actually constitutes a radical innovation and distinguishes it from an incremental innovation may depend upon the question being asked and the perspective in which innovative activity is being considered. Table 2 distinguishes across a broad spectrum of perspectives yielding somewhat different views on what distinguishes a radical innovation from an incremental innovation. For example, in terms of the time horizon, incremental innovations tend to realize their impact

within a shorter time period than do radical innovations. Similarly, the source and process of idea generation and opportunity recognition varies between incremental and radical innovation.

Table 3 Distinguishing Between Incremental and Radical Innovation

Focus	Incremental	Radical
Time frame	Short term- 6 to 24 months	Long term – usually 10 years plus
Development Strategy	Step after step from conception to commercialization, high levels of certainty	Discontinuous, iterative, set-backs, high levels of uncertainty
Idea generation and opportunity recognition	Continuous stream of incremental improvement; critical events largely anticipated	Ideas often pop up unexpectedly, and from unexpected sources, slack tends to be required; focus and purpose might change over the course of the development
Process	Formal, established, generally with stages and gates	A formal, structured process might hinder
Business case	A complete business case can be produced at the outset, customer reaction can be anticipated	The business case evolves throughout the development and might change; predicting customer reaction is difficult
Players	Can be assigned to a cross-functional team with clearly assigned and understood roles; skill emphasis is on making things happen	Skill areas required; key players may come and go; finding the right skills often relies on informal networks; flexibility, persistence and willingness to experiment are required
Development Structure	Typically, a cross-functional team operates within an existing business unit	Tends to originate in R&D; tends to be driven by the determination of one individual who pursues it wherever he or she is
Resources and skill requirements	All skills and competences necessary tend to be within the project team; resource allocation follows a standardized process	It is difficult to predict skill and competence requirements; additional expertise from outside might be required; informal networks; flexibility is required
Operating unit involvement	Operating units are involved	Involving operating units

from the beginning	too early can again lead to great ideas becoming small
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Source: Stamm (2003)

3. Entrepreneurship, Radical Innovation and the Knowledge Filter

An important and broadly accepted strand of literature suggests that small and new firms will be at a competitive disadvantage in generating innovative activity in general and radical innovations in particular. According to the Griliches (1979) model of the knowledge production function, innovative activity is the direct result of investments made by the firm in knowledge inputs, such as R&D and human capital. Since larger firms generally undertake significantly more investment in R&D than do small and new firms, they would be expected to generate more innovative activity.

Since radical innovation generates more value than does incremental innovation, some scholars have assumed and even developed elaborate theoretical models explaining why large firms, which have large R&D departments will generate more radical innovations than will small and new firms, which are constrained by size in their ability to invest in R&D (Cohen and Klepper, 1992a and 1992b).

Five factors favoring the innovative advantage of large enterprises have been identified in the literature. First is the argument that innovative activity requires a high fixed cost. As Comanor (1967) observes, R&D typically involves a

"lumpy" process that yields scale economies. Similarly, Galbraith (1956, p. 87) argues, "Because development is costly, it follows that it can be carried on only by a firm that has the resources which are associated with considerable size."

Second, only firms that are large enough to attain at least temporary market power will choose innovation as a means for maximization (Kamien and Schwartz, 1975). This is because the ability of firms to appropriate the economic returns accruing from R&D and other knowledge-generating investments is directly related to the extent of that enterprise's market power (Cohen and Klepper, 1990 and 1991; Levin et al., 1985 and 1987; and Cohen et al., 1987). Third, R&D is a risky investment; small firms engaging in R&D make themselves vulnerable by investing a large proportion of their resources in a single project. However, their larger counterparts can reduce the risk accompanying innovation through diversification into simultaneous research projects. The larger firm is also more likely to find an economic application of the uncertain outcomes resulting from innovative activity (Nelson, 1959).

Fourth, scale economies in production may also provide scope economies for R&D. Scherer (1991) notes that economies of scale in promotion and in distribution facilitate the penetration of new products, thus enabling larger firms to enjoy a greater profit potential from innovation. Finally, an innovation yielding cost reductions of a given percentage results in higher profit margins for larger firms than for smaller firms.

There is also substantial evidence that technological change -- or rather, one aspect of technological change, R&D, is, in fact, positively related to firm size. The plethora of empirical studies relating R&D to firm size is most thoroughly reviewed in Acs and Audretsch (2003). The empirical evidence is generally consistent with the hypotheses that large firms invest in proportionately more R&D.

Using a direct measure of innovative output from the U.S. Small Business Administration's Innovation Data Base, Acs and Audretsch (1990) shows that, in fact, the most innovative U.S. firms are large corporations. Further, the most innovative American corporations also tended to have large R&D laboratories and be R&D intensive. At first glance, these findings based on direct measures of innovative activity seems to confirm the conventional wisdom. However, in the most innovative four-digit standard industrial classification (SIC) industries, large firms, defined as enterprises with at least 500 employees, contributed more innovations in some instances, while in other industries small firms produced more innovations. For example, in computers and process control instruments small firms contributed the bulk of the innovations. By contrast in the pharmaceutical preparation and aircraft industries the large firms were much more innovative.

Probably their best measure of innovative activity is the total innovation rate, which is defined as the total number of innovations per one thousand employees in each industry. The large-firm innovation rate is defined as the number of innovations made by firms with at least 500 employees, divided by the number of employees (thousands) in large firms. The small-firm innovation rate is analogously

defined as the number of innovations contributed by firms with fewer than 500 employees, divided by the number of employees (thousands) in small firms.

The innovation rates, or the number of innovations per thousand employees, have the advantage in that they measure large- and small-firm innovative activity relative to the presence of large and small firms in any given industry. That is, in making a direct comparison between large- and small-firm innovative activity, the absolute number of innovations contributed by large firms and small enterprises is somewhat misleading, since these measures are not standardized by the relative presence of large and small firms in each industry. When a direct comparison is made between the innovative activity of large and small firms, the innovation rates are presumably a more reliable measure of innovative intensity because they are weighted by the relative presence of small and large enterprises in any given industry. Thus, while large firms in manufacturing introduced 2,445 innovations , and small firms contributed slightly fewer, 1,954, small-firm employment was only half as great as large-firm employment, yielding an average small-firm innovation rate in manufacturing of 0.309, compared to a large-firm innovation rate of 0.202 (Acs and Audretsch, 1988 and 1990).

What explains this innovation paradox, where small and new firms are empirically found to generate more innovative activity than would have been expected given their meager R&D resources? The resolution of this innovation paradox lies again in considering both the nature of knowledge within the context of the organizations creating that knowledge and the role of entrepreneurship, or what Audretsch et al. (2006) term the knowledge spillover theory of entrepreneurship.

As explained in the previous section, in the case of radical innovation, the expected economic value of a new idea, or knowledge, varies significantly across economic agents within any given organization and across different layers of decision makers. What seems like a good idea to one economic agent may not seem so good to her boss or her boss's boss. New ideas, technical or otherwise, are likely to generate a divergence of assessments about their potential value. While information involving incremental innovation tends to converge to a singular expected value across economic agents, by contrast new knowledge underlying radical innovation can generate a divergence in expected values across diverse economic agents.

Thus, because of the conditions inherent in radical innovation based on knowledge – high uncertainty, asymmetries and transactions cost – decision making hierarchies can reach the decision not to pursue and try to commercialize new ideas that individual economic agents, or groups or teams of economic agents think are potentially valuable and should be pursued. The characteristics of knowledge distinguishing it from information, a high degree of uncertainty combined with non-trivial asymmetries, combined with a broad spectrum of institutions, rules and regulations distinguish radical innovation from incremental innovation.

Thus, not all of the potential innovative activity, especially radical innovations created through scientific discoveries and inventions is fully appropriated within the firm making the investments to create that knowledge in the first place. Various constraints on the ability of large firm to evaluate the value of knowledge prevents it from fully exploiting the inherent value of its knowledge

assets (Moran and Ghoshal 1999). In fact, evidence shows that many large, established companies find it difficult to take advantage of all the opportunities emanating from their investment in scientific knowledge (Christenson and Overdorf 2000). For example, Xerox's Palo Alto Research Center is a vivid example highlighting a firm that succeeded in generating a large number of scientific breakthroughs (a superior personal computer, the facsimile machine, the Ethernet, and the laser printer, among others), yet failed to commercialize many of them and develop them into innovations (Smith and Alexander 1988; Chesbrough and Rosenbloom 2002).

The knowledge conditions inherent in radical innovation impose what Audretsch et al. (2006) and Acs et al. (2004) term *the knowledge filter*. The knowledge filter is the gap between knowledge that has a potential commercial value and knowledge that is actually commercialized in the form of innovative activity. The greater is the knowledge filter, the more pronounced is the gap between new knowledge and commercialized knowledge in the form of innovative activity.

An example of the knowledge filter confronting a large firm is provided by the response of IBM to Bill Gates, who approached IBM in 1985 to see if it was interested in purchasing the then struggling Microsoft. They weren't interested. IBM turned down, "the chance to buy ten percent of Microsoft for a song in 1986, a missed opportunity that would cost \$3 billion today."³ IBM reached its decision on the grounds that "neither Gates nor any of his band of thirty some employees had

³ "System Error," *The Economist*, September 18, 1993, p. 99.

anything approaching the credentials or personal characteristics required to work at IBM.”⁴

Thus, the knowledge filter serves as a barrier impeding investments in new knowledge from being pursued and developed to generate innovative activity. The knowledge filter can impede such knowledge investments from resulting in commercialized new products and/or processes. In some cases the firm will decide against developing and commercializing the new ideas emanating from its knowledge investments, even if an employee, or group of employees, think have a positive expected value. As explained above, the inherent conditions of uncertainty, asymmetries and high transactions costs leading to the knowledge filter that can result in a divergence in the expected value of a new idea between the incumbent firm or organization creating that knowledge and a worker, or economic agent employed by the firm.

While Griliches’ model of the knowledge production function focuses on the decision making context of the firm concerning investments in new knowledge, Audretsch (1995) proposed shifting the unit of analysis from the firm to the individual knowledge worker (or group of knowledge workers). This shifted the fundamental decision making unit of observation in the model of the knowledge production function away from exogenously assumed firms to individuals, such as scientists, engineers or other knowledge workers – agents with endowments of new economic knowledge. Shifting the lens away from the firm to the individual as the

⁴ Paul Carrol, “Die Offene Schlacht,” *Die Zeit*, No. 39, September 1993, p.18.

relevant unit of observation also shifts the appropriability problem to the individual, so that the relevant question becomes how economic agents with a given endowment of new knowledge can best appropriate the returns from that knowledge. If an employee can pursue the new idea within the context of the organizational structure of the incumbent firm, she has no reason to leave the firm. On the other hand, if she places a greater value on her ideas than does the decision-making hierarchy of the incumbent firm, she may face forgoing what she has evaluated as a good idea. Such divergences in the valuation of new ideas force the worker to choose between forgoing her idea or else starting a new firm to appropriate the value of her knowledge.

By focusing on the decision-making context confronting the individual, the knowledge production function is actually reversed. Knowledge becomes exogenous and embodied in a worker. The firm is created endogenously in the worker's effort to appropriate the value of his knowledge through innovative activity. Typically an employee in an incumbent large corporation, often a scientist or engineer working in a research laboratory, will have an idea for an invention and ultimately for an innovation. Accompanying this potential innovation is an expected net return from the new product. The inventor would expect compensation for his/her potential innovation accordingly. If the company has a different, presumably lower, valuation of the potential innovation, it may decide either not to pursue its development, or that it merits a lower level of compensation than that expected by the employee.

In either case, the employee will weigh the alternative of starting her own firm. If the gap in the expected return accruing from the potential innovation between the inventor and the corporate decision maker is sufficiently large, and if the cost of starting a new firm is sufficiently low, the employee may decide to leave the large corporation and establish a new enterprise. Since the knowledge was generated in the established corporation, the new start-up is considered to be a spin-off from the existing firm. Such start-ups typically do not have direct access to a large R&D laboratory. Rather, the entrepreneurial opportunity emanates from the knowledge and experience accrued from the R&D laboratories with their previous employers. Thus, entrepreneurship is an endogenous response to opportunities created by investments in new knowledge that are not commercialized because of the knowledge filter. By resorting to the startup of a new firm to actualize the commercialization of ideas that otherwise might remain dormant in the incumbent firm, entrepreneurship serves as a conduit for knowledge spillovers.

Knowledge created in one organizational context that remains uncommercialized due to the knowledge filter provides an important source generating new entrepreneurial opportunities. It is new knowledge and ideas created in one context but left uncommercialized or not vigorously pursued by the organization actually creating those ideas, such as a research laboratory in a large corporation or research undertaken by a university, that serves as the source of knowledge generating entrepreneurial opportunities. Thus, entrepreneurship can serve as an important mechanism facilitating the spillover of knowledge. The incumbent organization creating the knowledge and opportunities is not the same

firm that actually exploits the opportunities. If the exploitation of those opportunities by the entrepreneur does not involve full payment to the firm for producing those opportunities, such as a license or royalty, then the entrepreneurial act of starting a new firm serves as a mechanism for knowledge spillovers.

Thus, new knowledge generating opportunities for entrepreneurship is the duality of the knowledge filter. The higher is the knowledge filter, the greater are the divergences in the valuation of new ideas across economic agents and the decision-making hierarchies of incumbent firms. Entrepreneurial opportunities are generated not just by investments in new knowledge and ideas, but in the propensity for only a distinct subset of those knowledge opportunities to be fully pursued and commercialized by incumbent firms. Thus, the entrepreneurship is important in generating innovative activity in general and radical innovations in particular by serving as an important conduit of knowledge spillovers.

4. Literature Review Measuring and Defining Radical Innovation

“Innovation best comes from people who really know nothing about the topic. When I came to Kodak, I did not know much about cameras. When they asked me to experiment with the CCD (*charge-coupled device*), I did not know what to do.

I just tried an analogist's way to take pictures, I was no photography expert. I could not have built a conventional camera. The ideal way is not to just look to the experts, look to people who have a passion to explore, and those who are not afraid of making mistakes.

Thomas Edison was a prolific inventor and he was always surrounded by people who thought they were all better than him. Inventors spend most of the time being wrong and liking it, being comfortable with failure, because that is how you learn. Inventors

have to be resolute and the environment should be tolerant to you. You have to spend a lot of time being wrong than being right.”

Quote from Steven Sasson, inventor of the digital camera and 35 year employee of Eastman Kodak.⁵

4.1 Expert Panels

There is now a long tradition of relying on industry experts to identify innovative activity. The first serious attempt to directly measure innovative output was by a panel of industry experts assembled by the Gellman Research Associates (1976) for the National Science Foundation. The Gellman panel of experts identified 500 major innovations that were introduced into the market between 1953 and 1973 in the United States, the United Kingdom, Japan, West Germany, France, and Canada. The data base was compiled by an international panel of experts, who identified those innovations representing the "most significant new industrial products and processes, in terms of their technological importance and economic and social impact" (National Science Board, 1975, p. 100).

A second and comparable data base once again involved an expert panel assembled by the Gellman Research Associates (1982), this time for the U.S. Small Business Administration. In their second study, Gellman compiled a total of 635 U.S. innovations, including 45 from the earlier study for the National Science Foundation. The additional 590 innovations were selected from fourteen industry trade journals for the period 1970-1979. About 43 percent of the sample was

⁵ [“Innovation best comes from people who know nothing about the topic”](#)

selected from the award winning innovations described in the Industrial Research & Development magazine.

The third data source that has attempted to directly measure innovation activity was compiled at the Science Policy Research Unit (SPRU) at the University of Sussex in the United Kingdom.⁶ The SPRU data consist of a survey of 4,378 innovations that were identified over a period of fifteen years. The survey was compiled by writing to experts in each industry and requesting them to identify "significant technical innovations that had been successfully commercialized in the United Kingdom since 1945, and to name the firm responsible" (Pavitt et al., 1987, p. 299).

Another study completed by Audretsch and Acs use 4,938 innovations and as an expert panel to apply four levels of significance: (1) innovation established an entirely new category of product (2) innovation is the first of its type on the market for a product category already in existence (3) the innovation represents a significant improvement in technology and (4) the innovation is a modest improvement designed to update an existing product (Audretsch p.16)

Table 4 Distribution of Large and Small-firm Innovations According to Significance Levels (Percentages in Parentheses)

Innovation significance	Description	Number of Innovations		
		Large Firms		Small Firms

⁶ The SPRU innovation data are explained in considerable detail in Pavitt et al. (1987), Townsend et al. (1981), Robson and Townsend (1984), and Rothwell (1989).

1	Establishes whole new categories		(0.00)	(0.00)	(0.00)	(0.00)
2	First of its type on the market in existing categories		50	(1.76)	30	(1.43)
3	A significant improvement in existing technology		360	(12.70)	216	(10.27)
4	Modest improvement designed to update existing products		2,434	(85.53)	1,959	(88.31)
Total			2,834	(99.99)	2,104	(100)

Source: Audretsch and Acs (1990)

Audretsch and Acs find that while none of the innovations were at the highest significance level, they do find that small firms make up a considerable portion of the innovations within the field. There appears to be little difference in the “quality” and significance of innovations between large and small firms.

The most recent and most ambitious major data base providing a direct measure of innovative activity is the U.S. Small Business Administration's Innovation Data Base (SBIDB). The data base consists of 8,074 innovations commercially introduced in the U.S. in 1982. A private firm, The Futures Group, compiled the data and performed quality-control analyses for the U.S. Small

Business Administration by examining over one hundred technology, engineering, and trade journals, spanning every industry in manufacturing. Industry experts were relied upon both to identify innovations as well as their significance. From the sections in each trade journal listing innovations and new products, a data base consisting of the innovations by four-digit standard industrial classification (SIC) industries was formed. Many of the innovations were classified according to four distinct levels of significance, ranging from incremental, which referred to quality improvement, to most significant, which presumably referred to a radical innovation.⁷

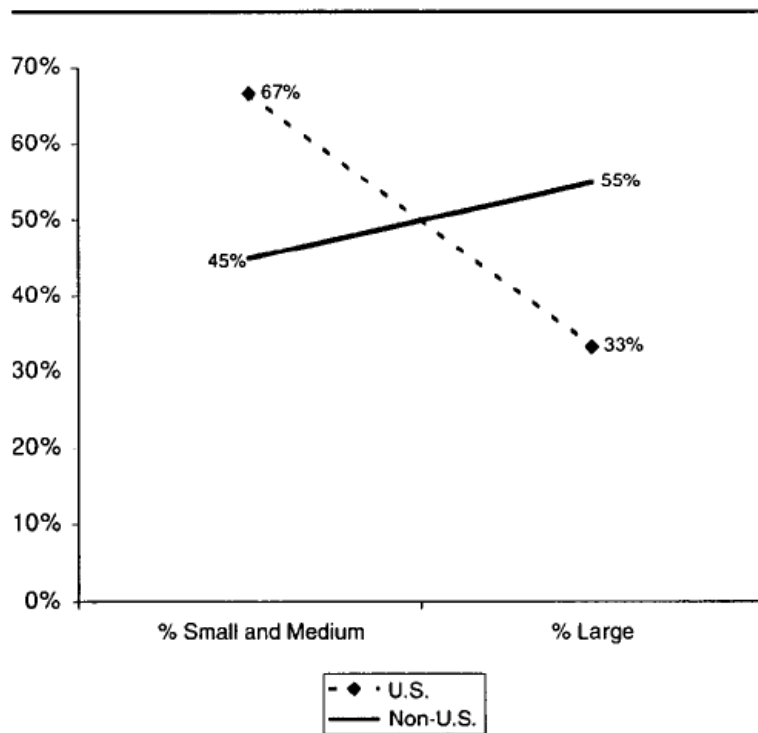
Dewar and Dutton (1986) similarly relied upon an ex post study of experts to identify specific radical innovations (1986, p. 1492) suggest that, “The major difference captured by the labels radical and incremental is the degree of novel technical process content embodied in the innovation and hence, the degree of new knowledge embedded in the innovation.” This distinction is consistent with those researchers who define technology in terms of its knowledge component (Dutton and Thomas 1985). Although radical and incremental pertain to distinctions along a theoretical continuum of the level of new knowledge embedded in an innovation, the middle values of this continuum are difficult to interpret (Baumol 2004).

Another study of expert panels find that there are large discrepancies between small and large firm innovation between the US and Non-us companies. As Chandy and Tellis (2000) show in figure one, the only 45 percent of small firms

⁷ A detailed description of the U.S. Small Business Administration’s Innovation Data Base can be found in chapter two of Acs and Audretsch (1990)

create radical innovations while 66 percent of US small firms created radical innovations in the market.

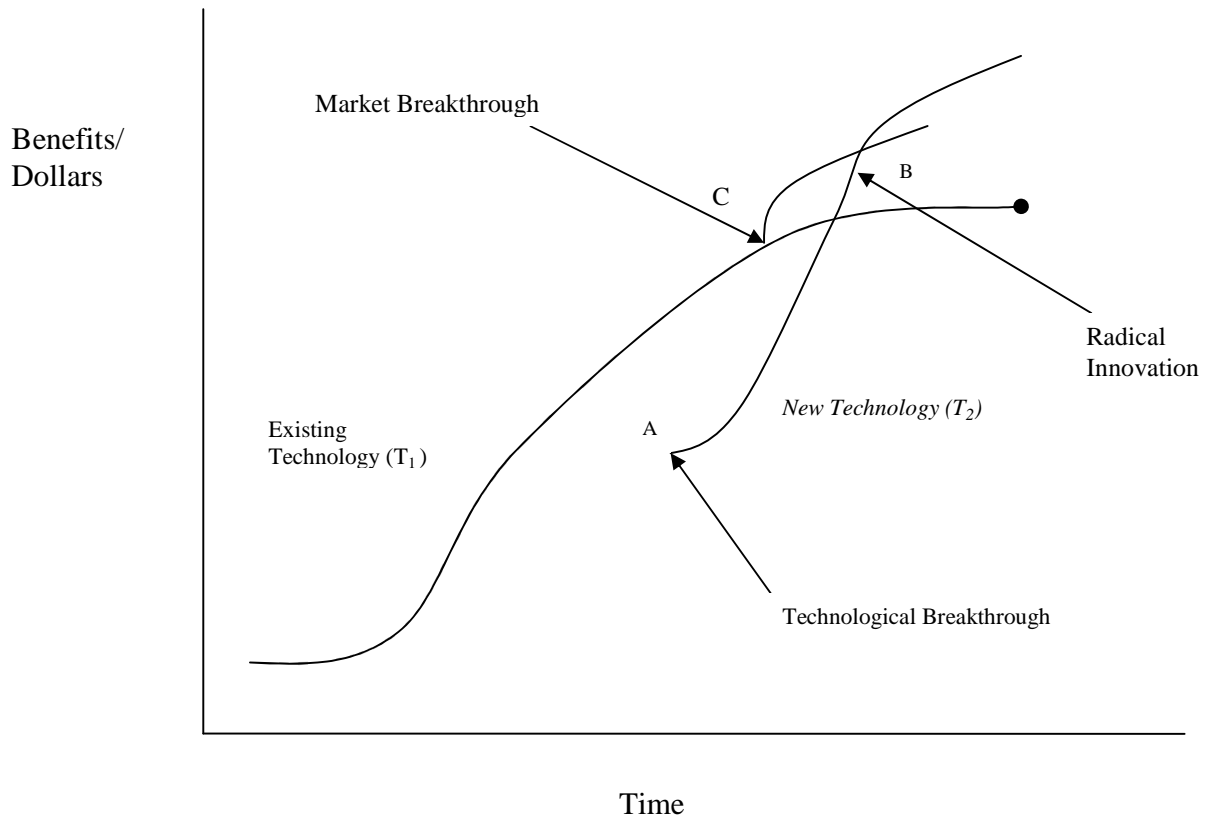
Figure 1 Radical Innovators by Size and Country for Consumer Durables and Office Products



4.2 S-curves and Technological Trajectories

Dosi introduces the theoretical discussion in 1982 by discussing how discontinuous and continuous technological trajectories can be distinguished. Much of the foundation for this area of research uses Schumpeterian economic evolution as a focal lens to understand the innovation process. In particular, Dosi develops a framework for distinguishing radical innovation from incremental innovation based on the technological push and consumer demand for innovation. Dosi suggests that an incremental innovation extends an existing technological paradigm. By contrast, a radical innovation creates a new technological paradigm. According to Dosi (1982, p.150) “Technological paradigms have a powerful *exclusion effect*: the efforts and the technological imagination of engineers and the organizations they are in are focuses in rather precise direction while they are, so to speak, ‘blind, with respect to other technological possibilities. At the same time, technological paradigms define also some idea of ‘progress.’” As shown in Figure 1, there are three points of innovation.

Figure 1 S-Curve of Radical Innovation



Source: Chandy and Tellis (2000) P.3

As Dahlin and Bohrens rightly point out: “A related approach suggests that the development of technologies subsequent to the introduction of a radical innovation will follow the path of an S-curve. However, as is the case for technological trajectories, s-curves do not offer a precise manner for mapping technologies. Neither do they help us identify, or define, the radical invention that will start a new S- curve. In effect, whereas we need to have good ideas about what

the important performance criteria are a priori, such ideas appear to us only a fortiori in Dosi and Foster's framework analyzing radical innovations.”

4.3 Hedonic Price Models

This strain of literature stems from Henderson and Clark (1990) and Henderson (1993) where price is the empirical measure used to determine radical innovation. Henderson studies the lithographic (publishing pictures) industry. While hedonic pricing traditionally limits itself to technological fields, it provides a quantifiable mean to understand the impact of variables on price. For example, instead of just measure the price of a black box camera to a digital camera, the model would adjust for incremental improvements in the process, such as a flash or quicker shutter speed. It therefore provides a simple way to understand how supplement additions in the quality of a product affect price. Henderson finds that “prior experience is significantly and negatively correlated with realized market share for radical innovation, providing strong support for the hypothesis that incumbents attempting to introduce products that require quite different organizational capabilities were severely handicapped” P.258

There are multiple problems with this method. The most crucial problem is that the method is unable to test for new fields that are dormant or in an emerging field. Indeed, *fifteen years prior to her study*, the radical innovation of the digital camera, was already owned and operated by the Kodak Eastman Company.⁸ Other problems with the method, for example, are that the hedonic price index approach

incorporates the productivity of individuals, and multiple product levels can be tested. However, one must pre select what product characteristics might predict the degree to which an innovation is radical. Another problem is that the willingness to pay may be more likely with incremental changes (Shane, 2001 and Tellis and Golde, 1996).

4.4 Codified Innovation: Patents

In the past twenty years, patents have become one of the most common means to measure the degree to which an innovation is radical or incremental. Patents have become an important metric in the innovation literature because of an easy and open paper trail of patent citations. This trail leaves a clearly defined origin of ideas and represents a clear lineage of where ideas go when they are cited in the future. This lineage comes in two forms: forward citations and backward citations. The patent citations also indicate a clear economic value to startups and economic growth (Trajtenberg, 1990). Since patent citations are equitable to a patent monopoly, there are strict procedures to ensure that appropriate citations are issued and therefore creating a platform for researchers to apply empirical investigation for radical innovation.

4.4.1 Forward Patent Citation Radicalness

Forward Patent citation involves future citations of a patent. These citations come from United States Patent Examiners. These professionals cite the previous patent only when there is a legitimate reason to cite the previous patent's intellectual property. These future citations are called forward patent citations.

Rosenkopf and Nerkar (2001) apply radicalness by examining the computer disk industry to investigate the impact patents have on future citations in domains of patent classification. Patent domains are maintained and categorized by the United States Patent and Trade Office (USPTO). The authors' show how incremental patents are often more narrowly cited within a certain domain of patents and radical patents are often cited by multiple domains of patents.

The patent forward count that Rosenknopf and Nerkar use is, in many ways, comparable to forward citations in scholarly journals. There are, however, two detrimental differences when using citations. First, there is a motivation from the patent inventor to cite as little as possible from previous work. The less work that is cited in the grant application, the more IP monopoly is granted to the inventor. Second, a patent examiner is required to assign relevant patent citations to the patent application. For a greater understand of defficiencies in the US patent examining process see (Graham and Harhoff 2006) (Harhoff et al. 2002). Drawing on patent citations creates other problems as well. As Rosenberg and Nekar define radical innovation: “‘radical’ exploration builds upon distant technology that resides outside of the firm. The technological subunit utilizes knowledge from a different technological domain and does not obtain that knowledge from other subunits with the firm.” P.290

The definition of radicalness holds innovation exogenous to the human capital and tacit knowledge of the firm. As Klepper and Graddy (1990) show new and radical innovations can, indeed, come from subunits within the firm. The distant technology can often be found within the incumbent firm. However, the firm is

unwilling to either operationalize the potential radical innovation due to managerial disagreements or unwilling to commit resources to a new and uncertain venture.

4.4.2 Backward Patent Classification and Citations

Another form of patent citations are backward citations. Shane (2001) then shows through a unique data set from MIT inventors involving 1397 licensed MIT patents, that the more radical the invention, the more likely it was made by a small firm. As Shane (2001), explains, radical innovations will tend to originate from small firms and large firms: P. 208 “First, radical technologies destroy the capabilities of existing firms because they draw on new technical skills. Since organizational capabilities are difficult and costly to create (Nelson and Winter, 1982; Hannan and Freeman, 1984), established firms are organized to exploit established technologies. Firms find it difficult to change their activities to exploit technologies based on different technical skills.”

The research finds that radical patent citations and a lack of patent classification are positive to startups for the MIT based patents.

4.5 Dahlin and Behrens Metric for Radicalness Innovations

While most industries experience a stream of inventions over time, a very small subset of these has the ability to single-handedly reconfigure the industry's bases of competition. Dahlin and Brehns (2005) use the tennis patent industry to show that there is not only a way to *ex ante* identify whether an invention is radical,

but also a way systematically analyze a product market to determine whether an invention was an important change agent or just a potential vehicle for change.

Dahlin and Behrens offer an attractive mean to identify incipient radical innovations a priori, or before they are actually fully developed and introduced. They create a three stage metric process which distinguishes between radical invention and radical innovation. This method offers a needed predictive power of identifying patents which have the potential to be a radical innovation. The three criterion they suggest are based on the structure of patent citations and replication of new patent citations.

The first criterion is based on how dissimilar the citation structure is of past patents cited. For example, if the radical patent is dissimilar from the traditional patent structure in the specific field, the patent fulfils the first criterion. The second uses concurrent patent citations structures a mean to understand how radically different the patent citation structure is from the average patent structure. The third criterion then follows the forward patent citations to estimate if the patent citation structure is replicated in future patents, i.e. the patent has future patents follow a similar patent citation structure.

Finally, as shown in Table 5, a literature summary on radical innovations offers the reader a more condensed understanding of the industries studied and the offered definition of radicalness.

Table 5 Literature Summary of Radical innovations

Commonly used definitions of radical vs. incremental changes		
Studies in chronological order	Industries studied	Definition of novelty
Cooper and Schendel (1976)	Locomotives, fountain pens, vacuum tubes, fossil fuel boilers, safety razors, propellers, leather	None. Selected industries in which almost full substitution occurred when innovation was introduced
Dosi (1982)	Theory paper	Technological paradigm = "model" and a "pattern" of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies (p. 152); radical change~ paradigm shift
Foster (1985)	Multiple examples, e.g. watches, artificial hearts, textile fibers, semiconductors	Discontinuity = gap between two s-curves at a point where one technology replaces another
Dewar and Dutton (1986)	Shoe manufacturing	Radical innovations require adopting firm to process new information
Anderson and Tushman (1990)	Glass, cement, and minicomputers	2 dimensions: (1) order-of-magnitude change in price-performance ratio; (2) competence-enhancing vs. competence -destroying
Henderson and Clark (1990)	Theory paper	2 dimensions: (1) design architecture is reinforced or changed; (2) core technological concepts in componentry are reinforced or changed
Henderson (1993)	Photolithographic alignment equipment	2 dimensions: (1) degree of substitutability; (2) competence-enhancing vs. competence -destroying
Das (1994)	Theory paper	2 dimensions: (1) knowledge same or different; (2) Competence-enhancing vs. competence -destroying
Christensen and Rosenbloom (1995)	Disk drives	Radical = launching new direction in technology vs. Incremental = making progress along established path
Christensen and Bower (1996)	Disk drives	Radical = disrupts or redefines a performance trajectory. Incremental = sustains the industry's rate of improvement in product performance
Tripsas (1997)	Graphical typesetting	None
Rosenkopf and Nerkar (2001)	Optical disk technology	"Radical exploration builds upon distant technology that resides outside of the firm." (p. 290)
Chandy and Tellis (2000)	Consumer durables and office products	"a new product that incorporates a substantially different core technology and provides substantially higher customer benefits relative to previous products in the industry" P.2
Van den Hoed (2006)	Automotive fuel cells	"a technology that builds on a different set of engineering and scientific principles that (i) substitutes for the established technology, and (ii) overturns the current competencies of the established industry." P. 1015

Shane (2001)	MIT licensed patents	"I measure the radicalness of the patent as a time-invariant count of the number of three-digit patent classes in which <i>previous</i> patents cited by the given patent are found, but the patent is not classified" P. 210
Ahuja and Lampert (2001)	Chemicals	Radical/breakthrough inventions "serve as the basis of 'future' technologies, products and services." (p. 522)

Adopted from Dahlin and Behrens (2005)

6. Conclusion

The interim report has shown there are a variety of different ways in which radical innovation is manifested. The report plans to further expand on the metrics of the Dahlin and Behrens model.

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