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Review of Radical Innovation in Small and Large Firms

David Audretsch and Taylor Aldridge
Max Planck Institute of Economics

Abstract. There is a surprising dearth of literature discussing radical innovations, yet, a common definition in either quantitative or qualitative terms has yet to emerge. This paper shows the genesis of radical innovation literature illustrates and how both small and large firms in differing degrees generate radical innovation. The paper then proceeds to distinguish the characteristics of incremental versus radical innovation. The paper then illustrates the uncertainty of whether small for large firms produce greater levels of radical innovation.

Keywords: radical innovation, knowledge filter, small firms, survey.

1. Introduction

Since the early days of Joseph Schumpter in the 1920s, the concept of radical innovation in economic theory has been a driving force for 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 radial innovative activity.

The following section of the paper will define innovation and offer broad definitions of radical innovation and offer a historical taxonomy of how scholarship has identified radical and incremental innovative activity. The third section will address how entrepreneurship relates to radical innovation and why the "knowledge spillover theory of entrepreneurship" may be the missing link for radical innovations and economic growth. The fourth section offers conclusions and suggestions to identify radical innovations in large and small firms.

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, about Schumpeter "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. 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.
>
> Hossein Eslambolchi, AT&T's CTO and president of AT&T labs. As quoted from Rao et al. P. 182 (2005)

In order to understand where radical innovations originate from, we first will offer a brief descriptive summary on who has delivered radical innovations. To better understand how heterogeneous the sources are of radical innovations. 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 economic growth have emerged. 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	Blackberry

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 in-house 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 producer 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, the impact of incremental innovations tend to be realized within a shorter time period than that of 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 placers 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 from the beginning	Involving operating units too early can again lead to great ideas becoming small

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; Levin et al., 1985 and 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) and (Pavit et al., 1987, in a similar study for the UK) 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 innova-tions 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.

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 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 order 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."[1] IBM reached its decision on the grounds that "neither Gates nor any of his band of thirty some employees had anything approaching the credentials or personal characteristics required to work at IBM." [2]

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

1. "System Error", *The Economist*, September 18, 1993, p. 99.
2. Paul Carrol,"Die Offene Schlacht", *Die Zeit*, No. 39, September 1993, p.18.

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 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. Conclusion

In this paper we offer a literature review of how radical innovation is quantified and the metrics applied for identifying radical innovation. As shown in the literature, there are conflicting empirical metrics identifying radical innovation. Consequently, there is conflicting empirical evidence on the propensity that small and large firms radically innovate. After all, according to the literature, it surely can not be that both large firms are “incompetent” and small firms are “inferior” for radical innovations. These empirical inconsistencies lay to some degree in how one may identify a radical invention.

The paper has provided a summary of the literature, a broad family of definitions for radical innovations and provided a set of measurable indicators for identifying radical innovation *ex ante*. While it will continue to be unclear what share of radical innovation originates from small and large firms, the ability to identify the invention will be the critical aspect for policy makers to then identify whether the invention is from a large or small firm. Therefore, the authors believe that radical innovation should not necessarily be analyzed under the large or small firm unit of analysis, but rather at identifying and tracking radical innovations in and coming out of the pipeline.

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