Product Innovations by Young and Small Firms

by

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Executive Summary

This paper examines the extent to which product innovations stem from small, young firms versus large, established firms by analyzing the patenting behavior of public firms derived from the NBER-Compustat database and assembling a dataset of private and public firms from the Thomas Register of American Manufacturers.

The Thomas Register evidence shows that small firms are surprisingly capable at inventing and managing products relative to large firms. Suppose a small firm is defined as one with fewer than 500 employees. In 2002, small firms had an average of 10.01 products, while large firms had an average of 21.44 products; thus, small firms had on average half the number of products per firm compared to large firms. However, a firm with median employment of 1,000 had 0.0214 products per employee, a firm with median employment of 375 had 0.0534 products per employee, and a firm with median employment of 15 had 0.8767 products per employee. Similar findings are obtained for 2007.

The NBER-Compustat evidence shows that small firms are more innovative per dollar of R&D than large firms, and the extent to which this occurs is decreasing in firm age; and young firms are more innovative per dollar of R&D than old firms, and the extent to which this occurs is decreasing in firm size. Define a young firm as below the median age and a small firm as below the median employment. Young small firms obtained on average 2.42 times more citations per dollar of R&D stock than young large firms; by contrast, old small firms are 2.05 times more productive at R&D than old large firms. Young small firms obtained on average 2.50 times more citations per dollar of R&D stock than old small firms; by contrast, young large firms are 2.12 times more productive at R&D than old large firms.

1 Introduction

What is the extent of product innovations by firms of different sizes and ages? Do new products tend to originate from entrepreneurial or established firms? These questions are answered by examining the patenting behavior of public firms, and by assembling a dataset of private and public firms on product innovations from the Thomas Register of American Manufacturers.

Over the last 20 years, economists have dramatically improved our theoretical understanding of how product innovations influence major aspects of macroeconomic performance. Not only has research explored the potential role that product creation and destruction has for explaining business cycle fluctuations (e.g., Shleifer 1986; Caballero and Hammour 1994; Ghironi and Melitz 2005), but economists have also examined the key role played by new and better products for long-run growth (e.g., Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1992; Klette and Kortum 2004). Despite the vast implications of the theoretical literature on product creation and destruction, the empirical analysis on the aggregate behavior and implications of product innovations lags far behind its theoretical counterpart. This gap has emerged largely because of data availability. This study documents the nature and extent of product innovations using a newly constructed database with special attention to implications for entrepreneurship and growth.

Our approach recognizes industry life-cycles and also aims to improve our understanding of product innovations as sources of industry life-cycles. Every industry is characterized by a life cycle (Gort and Klepper 1982; Klepper and Graddy 1990; Agarwal and Gort 2002): an industry is born by a product innovation, which leads to firm entry and sales growth; the number of firms rises until it reaches a peak; and then the market eventually reaches a steady state. In this sense, product innovations spur entrepreneurship and growth. The sources of the product innovations were not identified in these studies, and the contributions to growth stemming from the product innovations were not measured. Finally, anecdotal evidence suggests entrepreneurship is an important source of product innovations, especially in high-tech. Yet, a systematic economy-wide analysis of product innovations has not been performed, and their impact on entrepreneurship and growth remains unexplored.

To measure product innovations, the 2002 and 2007 directories of the Thomas Register of American Manufacturers were collected. The Thomas Register is particularly suitable for our purposes because it contains a complete listing of the product and service portfolio of each industrial establishment. Specifically, the Thomas Register covers over one million distributors, manufacturers, and service companies within 67,000-plus industrial categories; and it contains categorical information about the size of the establishment (measured by assets and employees) as well as its year of birth. Small subsets of the Thomas Register have been used in industry life cycle studies precisely for its detailed categorization of products and age and size profile of the establishment (Gort and Klepper 1982; Klepper and Graddy 1990; Agarwal and Gort 2002).

Our main reason for using Thomas Register for measuring product innovations is that products are defined at a much finer level than the product categorization available in Census of Manufactures. The finest product categorization in the Census that is usable for reliable analysis is 7-digit SIC code (or 10-digit NAICS code). This level of product categorization is still rather coarse for detecting product innovations at the firm level. For example, in 1992 Census of Manufactures, the Semiconductors and Related Devices Industry (SIC 3674) has four distinct 7-digit products associated with it: integrated microcircuits, transistors, diodes and rectifiers, and other semiconductor devices. However, each of these 7-digit product categories actually contains a broad range of finer products. For instance, integrated microcircuits include semiconductor networks, microprocessors, and MOS (Metal-Oxide Semiconductor) memory. As a result, a new product in the form of a new microprocessor type (such as a Digital Signal Processor) would not be captured as a product innovation using the census product classification. Thomas Register actually provides much more detailed product information than the 7-digit categories available from the Census, and therefore, is a better source of identifying individual product innovations that may not be classified as separate products under a given 7-digit product classification.

Most studies of firm-level innovation so far focus on public firms. There are numerous drawbacks associated with evidence on public firms for which patenting is used as the measure of innovative output. First, public firms are by definition already large and older than start-ups, and constitute only a small fraction of all firms in the U.S. economy. Therefore, there is a clear need for using data on private firms, which the Thomas Register includes. Second, patent counts and citations are not direct measures of product innovations. It is well-known that few patents are commercialized; and the patents that are commercialized do not necessarily give rise to new products and give birth to new industries. For these reasons, it is imperative that a detailed product-level study be performed that is not restricted to public firms. To the best of our knowledge, only the Thomas Register can provide the kind of detailed information on the product portfolio of a firm that is required to identify product innovations.

The Thomas Register evidence shows that small firms are surprisingly capable at inventing and managing products relative to large firms. Suppose a small (large) firm is defined as one with fewer (more, respectively) than 500 employees. In 2002, small firms had an average of 10.01 products, while large firms had an average of 21.44 products; thus, small firms had on average half the number of products per firm compared to large firms. However, a firm with median employment of 1,000 had 0.0214 products per employee, a firm with median employment of 375 had 0.0534 products per employee, and a firm with median employment of 15 had 0.8767 products per employee. These findings suggest that the efficiency with which companies invent and manage products declines considerably as they become larger. Similar findings are obtained for 2007.

To provide a benchmark against which the Thomas Register results can be compared, the innovation behavior (as measured by patenting) of young, small *public* firms versus old, large *public* firms is examined. This study utilizes the NBER patent dataset constructed by Hall et al. (2005), which covers all patents and their citations (in future patent filings) granted during 1965-95, obtained from the U.S. Patent and Trademark Office. The patent assignee names were matched with Compustat in order to obtain R&D stock (a cumulative sum of R&D expenditures), employment, sales, the industry of operation, and the age of the firm (measured by the number of years the firm has been public). To measure R&D productivity, citations per dollar of R&D stock, per employee, and per dollar of sales were used; and to measure firm size, employment, sales, and R&D stock were used.

Small firms are more innovative per dollar of R&D than large firms, and the extent to which this occurs is decreasing in firm age; and young firms are more innovative per dollar of R&D than old firms, and the extent to which this occurs is decreasing in firm size. These findings are robust to using the various measures of R&D productivity and firm size. Comparisons of mean R&D productivity across the firm size and age distributions illustrate the magnitudes involved. Define a young firm as below the median age and a small firm as below the median employment. Young small firms obtained on average 2.42 times more citations per dollar of R&D stock than young large firms; by contrast, old small firms are 2.05 times more productive at R&D than old large firms. Young small firms obtained on average 2.50 times more citations per dollar of R&D stock than old small firms; by contrast, young large firms are 2.12 times more productive at R&D than old large firms.

It was inferred that the evidence on public firms, wherein patenting is used as the measure of innovative output, points unambiguously to the fact that young, small firms are far more innovative than old, large firms. The drawback of this analysis is twofold. First, the analysis is restricted to public firms, which by definition are already large and older than start-ups. Second, patent counts and citations are not direct measures of product innovations. It is well-known that few patents are commercialized; and the patents that are commercialized do not necessarily give rise to new products and give birth to new industries. For these reasons, it is imperative that a detailed product-level study be performed that is not restricted to public firms. To the best of our knowledge, only the Thomas Register can provide the kind of detailed information on the product portfolio of a firm that is required to identify product innovations.

Our study provides important policy implications pertaining to the establishment of R&D-intensive ventures in general, and small firms and start-ups in particular. Innovations are an engine of growth, so the potential gain in welfare that arises from subsidizing small and/or young research-intensive firms is significant. In light of the fact that our study with the Thomas Register agrees with the evidence uncovered for public firms, in the sense that small, young firms are responsible for more product innovations per employee (or dollar of sales) than old, large firms, government policy should aim towards subsidizing innovation efforts in small, young firms so as to maximize the government's return on investment and the favorable impact of entrepreneurship on society.

This paper is structured as follows. Section 2 reviews the literature. Section 3 studies the sample we collected from the Thomas Register. Section 4 performs the analysis on patenting by public firms. Section 5 concludes.

2 Literature Review

This section reviews the literature on firm size, age, and innovation in sub-section 2.1; product entry and exit in sub-section 2.2; the product life cycles in sub-section 2.3; and radical innovations in sub-section 2.4.

2.1 Firm Size, Age, and Innovation

Since the writings of Schumpeter (1950), the relationship between a firm's size and the rate at which it innovates, usually measured by patent counts, has been scrutinized. Various theoretical arguments have been put forth supporting Schumpeter's initial hypothesis that *large* firms should be more innovative. Large firms have a comparative advantage since R&D may involve significant start-up costs and economies of scale and scope (Cohen et al. 1987). Complementarities between R&D and non-manufacturing activities, such as marketing, sales, and distribution, may be better developed within large firms (Cohen et al.). The larger is a firm, the greater is the return to reducing its costs of production by engaging in process innovations (Cohen and Klepper 1996a). Finally, large firms spread the risks of R&D by holding diversified portfolios, and so may invest in more risky projects, which typically earn a higher return (Holmstrom 1989).

With such theoretical arguments in favor of Schumpeter's hypothesis, it is perhaps surprising that the exact opposite has been verified empirically. Specifically, within industries, the number of innovations per dollar of R&D *decreases* with firm size, and smaller firms account for a disproportionately large number of innovations relative to their size (Cohen and Klepper 1996b, Bound et al. 1984, Acs and Audretsch 1988, 1991a, Pavitt et al. 1987), though this is not true in all industries (Acs and Audretsch 1987). For example, Acs and Audretsch (1991b) find that small firms contribute 2.4 times more innovations per employee than do large firms.

The evidence in Prusa and Schmitz (1994) suggests that young firms are more innovative than old firms. The authors find that, in the PC software industry, a firm's initial product tends to be its most successful: a firm's initial product sells better than its second, its second sells better than its third, and so on. Furthermore, most innovations in an industry occur in its early stages, when industries tend to be dominated by start-ups (Jovanovic and MacDonald 1994, Klepper 1996, Agarwal and Gort 1996).

Models of entrepreneurship and spinoffs support our notion that small, young firms base themselves around a high quality idea. In Klepper and Thompson (2010), if a relatively well-informed manager sufficiently disagrees with the strategy of other managers, a spinoff occurs: the manager leaves the firm to better implement the idea in a start-up. In Chatterjee and Rossi-Hansberg (2007), workers have ideas for new projects that can be sold to existing firms or implemented in new firms; because the quality of their ideas are private information, workers with the best ideas launch spinoffs. The theories of entrepreneurship in Hellman (2007), Parker (2003), and Braguinsky et al. (2009) have similar interpretations and implications.

The literature provides numerous theoretical and empirical explanations of the negative relationship between firm size and R&D productivity. In Klepper (1996), the competitive advantage conferred by firm size accounts for the stylized fact that small firms are more innovative per dollar of R&D. By applying their R&D to a higher level of output, larger firms appropriate a greater fraction of the value of their R&D than smaller firms, inducing them to perform more R&D. Because of decreasing returns to R&D, their productivity at R&D is lower. In Kim and Marschke (2005), the risk of a scientist's departure reduces a firm's R&D expenditures and raises its propensity to patent an innovation. The authors provide evidence that scientists' turnover partly accounts for why small firms have high patent-R&D ratios. Zenger (1994) provides evidence that small high-tech firms attract and retain engineers with higher ability by offering them performance-based contracts. In Plehn-Dujowich (2009), efficient firms become larger and perform more process and product R&D; because of decreasing returns to R&D, this implies small firms generate more innovations per dollar of R&D than large firms.

2.2 Product Entry and Exit

Our study will complement the seminal work by Dunne, Roberts, and Samuelson (1988) and Davis and Haltiwanger (1992) by directly exploring a major element of the Schumpeterian creative destruction process: *product* entry (and exit). This is the key mechanism through which the creative process has an impact on the welfare of consumers. This study also documents the basic properties of product creation and destruction in ways similar to the literature on job turnover (e.g., Campbell 1998; Caballero and Hammour 1994). This is closely related to the literature on innovation cycles and in particular to the work of Shleifer (1986).

Bernard et al. (2010) studied the tendency of firms to add and drop products using the pooled 1987 to 1997 censuses. While the authors do not examine new product introductions, or from which firms product innovations originate, their findings suggest that there is ample turnover in a firm's product portfolio. Some of their findings are summarized below.

An average of 54 percent of surviving firms alter their mix of products every five years, 15 percent by dropping at least one product, 14 percent by adding at least one product, and 25 percent by both adding and dropping at least one product. An average of 89 percent of all manufacturing output is produced by firms that change their mix of products across census years. Firms that both add and drop products account for the largest share of output, at 68 percent. Net product adding is associated with an increase in firm size (whether measured by output or employment) as well as revenue-based labor and total factor productivity (TFP). Similarly, net product dropping is associated with a decrease in firm size and TFP. On average, 26 and 31 percent of firm output in 1992 and 1997, respectively, is represented by products firms added within the previous five years. A comparable average share of firm output, 29 and 26 percent for 1987 and 1992, respectively, is accounted for by about-to-be-dropped products.

Roughly two-thirds of the average product's output is produced by incumbents. The remaining output is more or less evenly split between firms adding or dropping the product and entering or exiting firms. In 1992, adders and entrants are responsible for an average of 14 and 19 percent of products' output, respectively, while droppers and exiters account for 15 and 18 percent, respectively. Next consider the share of firms producing a product in a census year. While incumbents make the greatest single contribution, their average share of firms, at 40 to 45 percent, is lower than their average share of output. Of the remaining 55 to 60 percent of producers, 29 to 37 percent are entering or exiting firms and 23 to 27 percent are adders or droppers. While there is some variation across sectors, there are substantial contributions of roughly equal magnitude from adders and droppers and entering and exiting firms in each two-digit manufacturing sector. 15 percent of the average product's 1992 output is accounted for by firms that subsequently drop the product, while 15 percent of 1997 output is due to firms that just added it. Over the same period, the change in the average share of output represented by incumbents was just 3 percent (from 67 to 70 percent).

2.3 The Product Life Cycles

Using the Thomas Register, Gort and Klepper (1982) study the birth of 46 new products to discover that a common trend emerges in the number of producers.[1] Every new product undergoes five stages that constitute its life cycle. Stage I begins with the introduction of the new product by its first producer, which triggers a wave of entry by competitors. Stage II is a period of dramatic growth, such that there is a stark increase in the number of producers. In Stage III, the number of producers reaches a maximum, representing the final segment of Stage

[1] The products are varied, including computers, electric blankets, rocket engines, lasers, zippers, and shampoo.

II. Stage IV is characterized by a “shakeout,” wherein the number of producers declines. By Stage V there are relatively few producers. In studying the evolution of 23 products from the Thomas Register, Klepper and Graddy (1990) confirm these results, and show that the life cycle can be summarized by three stages. Furthermore, three other patterns are identified in these studies that emerge clearly over the life cycle: aggregate output and output per firm rise at decreasing rates, while the price falls at a decreasing rate. Utterback (1994) contains various case studies with the same patterns, and Agarwal and Gort (2002) have similar findings. Jovanovic and MacDonald (1994) show graphically that the described patterns in output, prices, and the number of producers also apply to the automobile tire industry. Klepper and Simons (2000) study this industry as well and arrive at similar conclusions pertaining to the product life cycle.

2.4 Radical Innovations

Golder, Shacham, and Mitra (2009) examine the process of how radical innovations develop. The authors argue that there are three events in pre-commercialization: First Concept, First Prototype, and Commercialization. There are three stages culminating in these events: Conceptualization, Gestation, and Incubation. Furthermore, Commercialization is divided into Micro-commercialization and Macro-commercialization along with Early Incubation and Late Incubation. The process from Micro-commercialization to Macro-commercialization is called Late Incubation and is considered to be the Introduction stage of the product life cycle. The authors restrict their investigation to radical innovations for two reasons. First, radical innovations are more crucial to companies and societies because of their ability to create entire new industries and destroy existing ones (in the sense of Schumpeterian creative destruction). Second, firms have cumulated knowledge about incremental innovations because they develop scores of innovations of this kind, thus allowing compilation of common characteristics. Research on radical innovation has coalesced around two definitions. One requires an innovation to have a “substantially different core technology and provide substantially higher customer benefits relative to previous products in the industry” (Chandy and Tellis 2000, p. 2; Leifer et al. 2000). The second requires advancing “the price/performance frontier by much more than the exiting rate of progress” (Gatignon et al. 2002, p. 1107; Leifer et al. 2000). The common factor in these definitions is higher product performance leading to significantly higher customer benefits.

Golder, Shacham, and Mitra compile a sample of 29 radical innovations that have substantial new benefits to customers, focusing on their pre-commercialization period. 26 of the 29 innovations overlap with previous studies (Agarwal and Bayus 2002; Chandy and Tellis 2000; Golder and Tellis 1993, 1997; Kohli et al. 1999). The authors divide the innovations into three time periods: Pre-1900, 1900-1945, and Post-1945 based on the year the innovation was first sold. Examples in Pre-1900 include the telegraph and phonograph; in 1900-1945 they include radio, B&W TV, and tape recorder; and in Post-1945 they include the microwave, cell phone, and laser printer. The authors find that 38% of firms with the first concept also develop the first prototype, 59% of firms with the first prototype are also the first to sell the innovation, and 24% of firms that are first to micro-commercialize an innovation are also first to macro-commercialize it. Their findings suggest there is a strong negative relationship between leadership persistence and duration time.

3 Product Innovations as Measured by the Thomas Register

The Thomas Register of American Manufacturers is a directory of product information covering over one million distributors, manufacturers, and service companies within 67,000-plus industrial categories (depending on the year). Data was collected from the 2002 and 2007 Thomas Register directories. The Thomas Register provides a correspondence from the set of product/services categories to the set of companies. A "company" is defined as an establishment located at a single address. Company information includes the following: company name, address, contact information, company number in the Thomas Register, range of the number of employees, range of assets, year established, and parent/subsidiaries. All activities of each company can be tracked by the company number that is assigned in the Thomas Register. If a company is merged or the company name is altered for other reasons, the company number is kept the same. For every company listed in the Thomas Register, product and service categories are assigned by the Thomas Register: a group of experts classify companies into categories based on the description offered by each company. The Thomas Register thereby allows for the revelation of new products in the market. Products and services added by firms can be identified as new versus existing. Thus, product innovations can be distinguished comprehensively by examining changes in the list of products and services.

In the course of this study, technical problems were discovered with the archived CD-ROMs stored and provided by the Thomas Register; thus, the complete records of their historical files were not able to be obtained. The Thomas Register is fundamentally an online, timely database, focusing on providing current information on the product portfolio of companies. They previously published CD-ROMs of historical records that are archived in a handful of universities, but problems were discovered with those files due to their formatting being done improperly. In lieu of relying on the corrupted data in the CD-ROMs, a random sample of the Thomas Register was obtained from their historical records that were cached on old websites to gauge some of the Thomas Register's basic univariate properties.

Analysis of the Thomas Register sample depicts a rich, dynamic environment with stark differences between small versus large firms. In 2002, there were over 38,000 product and service categories, and over 150,000 companies. The average number of products per firm was 8.25, with a staggering maximum of 3,378. Table 1 provides an overview of the firm size and age distributions, and how they correlate with the number of products. A company with less than $1 million in assets had 4.35 products on average, and a company with less than 10 employees had 3.89 products on average. Suppose a small (large) firm is defined as one with less (more, respectively) than $250 million in assets or less (more, respectively) than 500 employees. Using assets as the measure of size, small firms (which accounted for 41.91% of the sample) had an average of 10.40 products per firm, while large firms (which accounted for 1.32% of the sample) had an average of 19.14 products per firm. Using employment as the measure of size, small firms (which accounted for 32.10% of the sample) had an average of 10.01 products per firm, while large firms (which accounted for 0.53% of the sample) had an average of 21.44 products per firm. Therefore, overall, in 2002, small firms had on average half the number of products per firm compared to large firms. Given the stark differences in capabilities and resources between small versus large firms, this demonstrates an impressive ability of small firms to invent and/or manage a large product portfolio.

Table 1 Panel C provides the average number of products per firm as a function of firm age. Older firms tend to have more products than younger firms, paralleling the results found for large versus small firms. Firms established in 1958 and earlier had over 10 products, while firms established after 1958 had between 5 and 9 products per firm.

Table 1 Panels A and B demonstrates that the average number of products per firm clearly increases with firm size, though at a decreasing rate. This phenomenon is further explored in the next table. Table 2 provides an overview of the number of products per firm as a function of size. The exact size of a company is not known since Thomas Register respondents solely report a size range. Therefore, it was assumed all companies in a size range have the median size of that size range; and for the largest size range, it was assumed the median is twice the lower end of the range (that is, the median assets for the over $250 million in assets group is $500 million in assets, and the median employment for the over 500 in employment group is 1000 employees). Table 2 Panel A reveals that the average number of products per firm per $1,000 in assets declines steadily the larger is the firm (as measured by assets). For example, companies with $500,000 in assets have an average of 0.0087 products per $1000 in assets, while companies with $2.5 million in assets have an average of 0.0042. A similar pattern is revealed in Table 2 Panel B when size is measured using employment, though there is a slight increase from the 5 to 15 employment groups. The numbers are quite dramatic: a firm with median employment of 1,000 has 0.0214 products per employee, while a firm with median employment of 5 has 0.7780 products per employee. These findings suggest that the efficiency with which companies invent and manage products declines considerably as they become larger.

Table 1: Descriptive Statistics of the 2002 Thomas Register

Panel A: Distribution of Sample by Assets

Assets	No. of companies	%	Average no. of products per firm
Under $1,000,000	16798	10.93%	4.35
$1,000,000-4,999,999	24532	15.96%	10.57
$5,000,000-9,999,999	10377	6.75%	14.65
$10,000,000-24,999,999	6139	3.99%	15.37
$25,000,000-49,999,999	2827	1.84%	13.90
$50,000,000-99,999,999	2749	1.79%	14.41
$100,000,000 -249,999,999	999	0.65%	12.43
Below $250,000,000 (“Small”)	64421	41.91%	10.40
Over $250,000,000 (“Large”)	2030	1.32%	19.14
Not Rated	79551	51.76%	6.81
Not Reported	7677	5.00%	

Panel B: Distribution of Sample by Employment

Employment	No. of companies	%	Average no. of products per firm
Under 10	25655	16.69%	3.89
10 – 19	5516	3.59%	13.15
20 – 49	7897	5.14%	16.30
50 – 99	4687	3.05%	18.29
100 – 249	4164	2.71%	18.85
250 – 499	1416	0.92%	20.01
Under 500 (“Small”)	49335	32.10%	10.01
Over 500 (“Large”)	807	0.53%	21.44
Not Reported	103537	67.37%	

Panel C: Distribution of Sample by Year Established

Year Established	No. of companies	%	Average no. of products per firm
1999 – 2001	1183	0.77%	5.10
1989 – 1998	12705	8.27%	6.48
1979 – 1988	18767	12.21%	7.45
1969 – 1978	15185	9.88%	7.96
1959 – 1968	9768	6.36%	9.13
1949 – 1958	6959	4.53%	10.54
1939 – 1948	5713	3.72%	11.27
1929 – 1938	2853	1.86%	9.81
1919 – 1928	2640	1.72%	11.43
Before 1918	5843	3.80%	11.96
Not Reported	72059	46.89%	

Notes: authors’ calculations based on a random sample from the 2002 Thomas Register.

Table 2: Number of Products per Firm as a Function of Size for the 2002 Thomas Register
Panel A: Distribution of Sample by Assets

Median assets	No. of companies	%	Average no. of products per firm	Average no. of products per firm per $1,000 in assets
$500,000	16798	10.93%	4.35	0.0087
$2,500,000	24532	15.96%	10.57	0.0042
$7,500,000	10377	6.75%	14.65	0.0020
$17,500,000	6139	3.99%	15.37	0.0009
$37,500,000	2827	1.84%	13.9	0.0004
$75,000,000	2749	1.79%	14.41	0.0002
$175,000,000	999	0.65%	12.43	0.0001
$500,000,000	2030	1.32%	19.14	0.0000

Panel B: Distribution of Sample by Employment

Median employment	No. of companies	%	Average no. of products per firm	Average no. of products per firm per employee
5	25655	16.69%	3.89	0.7780
15	5516	3.59%	13.15	0.8767
35	7897	5.14%	16.3	0.4657
75	4687	3.05%	18.29	0.2439
175	4164	2.71%	18.85	0.1077
375	1416	0.92%	20.01	0.0534
1000	807	0.53%	21.44	0.0214

Notes: authors' calculations based on a random sample from the 2002 Thomas Register.

Table 3 describes the sample for 2007. There were over 47,000 product and service categories, and over 130,000 companies. The average number of products per firm was 13.18, with a surprising maximum of 6,043. There are great differences in product scope across the firm size distribution. A company with less than $1 million in assets had 6.69 products on average, and a company with less than 10 employees had 5.46 products on average. By contrast, a company with over $250 million in assets had 26.98 products on average, and a company with over 500 employees had 16.77 products on average. As before, suppose a small (large) firm is defined as one with less (more, respectively) than $250 million in assets or less (more, respectively) than 500 employees. Using assets as the measure of size, small firms (which accounted for 38.82% of the sample) had an average of 16.36 products per firm, while large firms (which accounted for 1.35% of the sample) had an average of 26.98 products per firm. Using employment as the measure of size, small firms (which accounted for 67.71% of the sample) had an average of 12.00 products per firm, while large firms (which accounted for 1.15% of the sample) had an average of 16.77 products per firm. Therefore, overall, in 2007, large firms had on average about fifty percent more products per firm compared to small firms. This represents a marked decline in the difference between small versus large companies compared to 2002, which may be due to the deep technological changes experienced by the economy during that time.

Table 3 Panel C reveals that, as occurred in 2002, old firms tend to have a larger product portfolio than young firms. The differences are quite stark, with firms established before World War II having between fifteen and eighteen products per firm, whereas companies established in the Internet age have less than ten on average.

Table 4 calculates the efficiency with which companies invented and managed products in 2007. Table 4 Panel A reveals that companies with a median of $500,000 in assets had 0.0134 products per $1,000 in assets, while companies with a median of $500 million in assets had 0.0001 products per $1,000 in assets. Similarly, Table 4 Panel B shows that companies with a median employment of 5 had 1.0920 products per employee, while companies with a median employment of 1,000 had 0.0168. The evidence thereby suggests that, even in 2007, small firms were far more effective at inventing and managing products compared to large firms.

Table 3: Descriptive Statistics of the 2007 Thomas Register

Panel A: Distribution of Sample by Assets

Assets	No. of companies	%	Average no. of products per firm
Under $1,000,000	12975	9.49%	6.69
$1,000,000 - 4,999,999	20697	15.14%	16.24
$5,000,000 - 9,999,999	8797	6.44%	22.99
$10,000,000 - 24,999,999	5310	3.89%	24.24
$25,000,000 - 49,999,999	2404	1.76%	20.48
$50,000,000 - 99,999,999	2033	1.49%	24.14
$100,000,000 - 249,999,999	838	0.61%	19.13
Under $250,000,000 ("Small")	53054	38.82%	16.36
Over $250,000,000 ("Large")	1840	1.35%	26.98
Not Rated	81759	59.82%	10.80
Not Reported	24	0.02%	

Panel B: Distribution of Sample by Employment

Employment	No. of companies	%	Average no. of products per firm
Under 10	24297	17.78%	5.46
10 – 19	19845	14.52%	12.44
20 – 49	23683	17.33%	14.37
50 – 99	12250	8.96%	15.64
100 – 249	9331	6.83%	15.52
250 – 499	3129	2.29%	17.38
Under 500 ("Small")	92535	67.71%	12.00
Over 500 ("Large")	1569	1.15%	16.77
Not Reported	42573	31.15%	

Panel C: Distribution of Sample by Year Established

Year Established	No. of companies	%	Average no. of product per firm
1999 – 2006	3727	2.73%	5.56
1989 – 1998	14751	10.79%	8.77
1979 – 1988	18641	13.64%	11.56
1969 – 1978	14824	10.85%	13.28
1959 – 1968	9353	6.84%	14.85
1949 – 1958	6832	5.00%	16.58
1939 – 1948	5590	4.09%	19.46
1929 – 1938	2710	1.98%	15.09
1919 – 1928	2475	1.81%	18.02
Before 1918	5436	3.98%	18.83
Not Reported	52333	38.29%	

Notes: authors' calculations based on a random sample from the 2007 Thomas Register.

Table 4: Number of Products per Firm as a Function of Size for the 2007 Thomas Register
Panel A: Distribution of Sample by Assets

Median assets	No. of companies	%	Average no. of products per firm	Average no. of products per firm per $1,000 in assets
$500,000	12975	9.49%	6.69	0.0134
$2,500,000	20697	15.14%	16.24	0.0065
$7,500,000	8797	6.44%	22.99	0.0031
$17,500,000	5310	3.89%	24.24	0.0014
$37,500,000	2404	1.76%	20.48	0.0005
$75,000,000	2033	1.49%	24.14	0.0003
$175,000,000	838	0.61%	19.13	0.0001
$500,000,000	1840	1.35%	26.98	0.0001

Panel B: Distribution of Sample by Employment

Median employment	No. of companies	%	Average no. of products per firm	Average no. of products per firm per employee
5	25655	16.69%	3.89	0.7780
15	5516	3.59%	13.15	0.8767
35	7897	5.14%	16.3	0.4657
75	4687	3.05%	18.29	0.2439
175	4164	2.71%	18.85	0.1077
375	1416	0.92%	20.01	0.0534
1000	807	0.53%	21.44	0.0214

4 Product Innovations as Measured by Patenting

This section examines the relationship between firm size, age, and innovation across public firms using patenting as the measure of innovative output. This analysis is performed to compare our results to those obtained for private and public firms using the Thomas Register.

Sub-section 4.1 describes the Compustat sample. Sub-section 4.2 presents descriptive statistics and univariate analysis. Sub-section 4.3 performs regressions.

4.1 The Compustat Sample

To measure innovative output, patents are utilized. This study draws upon the NBER patent dataset constructed by Hall et al. (2005), hereby referred to as HJT. HJT obtained from the U.S. Patent and Trademark Office (USPTO) all patents granted during the period 1965-95, including their citations (in future patent filings); and, for 50-65% of the patents (depending on the year), matched the patent assignee names from the USPTO with corporations in Compustat, from which they obtained R&D expenditures, employment, sales, and the 2-digit SIC industry to which the firms belong. HJT constructed a variable termed "R&D stock" which is a cumulative sum of R&D expenditures going back to 1965, applying a depreciation rate of 15 percent. By employing the stock variable instead of contemporaneous R&D expenditures as the measure of R&D, the possibility that patents applied for in a given year were the result of earlier research is allowed. Sales and R&D stock in 2000 millions are expressed using the GDP deflator.

This study obtained the year in which each firm first appeared in Compustat, going back to 1950 (the first year of data available), referred to as the "year of birth." The current year of an observation minus the year of birth is referred to as "firm age." This is not a measure of a firm's actual age, but it is a reasonable proxy if the number of years it takes a firm to become public does not vary systematically with firm characteristics.[2] Because the age of a firm with the year of birth equal to 1950 cannot be ascertained, such observations are excluded. This implies the age distribution is censored.

A drawback of using patents to measure innovative output is that patent quality varies. Trajtenberg (1990) and HJT show that the number of citations received by a patent (in future patent filings) is an accurate indicator of the patent's economic impact and significantly affects the market value of the patent holder, so it is an appropriate method to account for varying patent quality. HJT document that it may take many years for a patent to receive citations. Thus, only observations from the years 1965-90 are included, allowing a patent a minimum of 5 years to receive citations (and a maximum of 30 years).[3] Hence, the citations distribution is truncated. Similar results to those reported here are obtained if one uses counts instead of citations.

Firm size is measured using employment, sales, and R&D stock. R&D productivity is measured using citations per dollar of R&D stock. To calculate R&D productivity, it is necessary to exclude observations with zero R&D stock. Bound et al. (1984) and others have found that the likelihood of reporting R&D expenditures is correlated with firm size. By only including R&D-performing firms, selection bias may be introduced if small firms that report R&D are more likely to be successful at research than small firms that do not report R&D. Rather than attempt to correct for the potential selection bias, alternative measures of R&D productivity are considered that do not require excluding firms that do not report R&D: citations per employee and per dollar of sales are used. Since regressions are run in logs, when using these alternative measures of R&D productivity, firm size is measured using employment and sales (and not R&D stock).

Following these procedures, for R&D-performing firms, an unbalanced panel with 8,758 firm-year observations is obtained; and for all firms, an unbalanced panel with 12,742 observations is obtained. In both samples, each firm has on average 11 years of observations, with a maximum of 26 years; and the average observation is in 1984.

[2] The number of years it takes a firm to become public can vary across industries because we include industry fixed effects in the regressions.
[3] Our regression results are robust to changing the sample period over the range 1965-1995.

Table 5 contains for R&D-performing firms the mean, median, and standard deviation of employment, sales, R&D stock, age, and citations per dollar of R&D stock. The firm size distribution is considerably right-skewed: the means of employment, sales, and R&D stock are over three times greater than their respective medians. The average size firm has 906 employees, sales of 133 million, and an R&D stock of 22 million. The age distribution is close to being symmetric, having a median of 18 years and a mean of 17 years. Over seventy percent of observations have no citations, thus the citations distribution is highly right-skewed. On average, 0.92 citations were obtained per dollar of R&D stock.

Table 5: Descriptive Statistics, R&D-Performing Firms

	Mean	Median	Std Dev
Employment	0.9062	0.2900	2.0655
Sales	132.8150	33.9090	366.3534
R&D stock	21.6763	5.7129	72.6727
Age	16.9567	18.0000	4.4987
Citations/R&D stock	0.9172	0.0000	13.7493

Notes: "Employment" is in thousands; "Sales" is in 2000 millions; "R&D stock" is the discounted sum of R&D expenditures in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; observations with zero R&D stock are excluded; there are 8,758 observations; the dataset is from Hall et al. (2005) and Compustat.

Table 6 contains for all firms the mean, median, and standard deviation of employment, sales, age, citations per employee, and citations per dollar of sales. The average size firm has 977 employees and sales of 145 million. Surprisingly, firms in this sample are larger than firms in the sample that only includes R&D-performing firms. This is a feature of the HJT dataset, and not an artifact of our exclusions. Over seventy-five percent of observations have no citations, so the citations distribution is even more right-skewed, which follows from the fact that most firms with zero R&D stock obtained no patents. Firms are slightly younger in this sample, having a median age of 17 years. On average, 13.50 citations were obtained per employee, and 0.44 per dollar of sales.

Table 6: Descriptive Statistics, All Firms

	Mean	Median	Std Dev
Employment	0.9769	0.3440	2.0488
Sales	145.2276	42.1280	374.0725
Age	16.5567	17.0000	4.7468
Citations/employee	13.5023	0.0000	90.1622
Citations/sales	0.4395	0.0000	20.1884

Notes: "Employment" is in thousands; "Sales" is in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; there are 12,742 observations; the dataset is from Hall et al. (2005) and Compustat.

4.2 Descriptive Statistics and Univariate Analysis

Table 7 contains the correlation coefficients between employment, sales, R&D stock, age, and citations per dollar of R&D stock for R&D-performing firms. As one would expect, the three measures of firm size are highly correlated, ranging from a correlation of 0.5832 between R&D stock and employment to 0.7767 between sales and employment. Firm age and size have a small positive correlation, ranging from 0.0001 (with employment) to 0.1007 (with R&D stock). This demonstrates that including age and size on the right-hand side of a regression should not pose a risk of multicollinearity, thereby allowing us to separately identify the effects of age versus size. All three measures of firm size, together with firm age, are weakly negatively correlated with R&D productivity.

Table 7: Correlation Coefficients, R&D-Performing Firms

	Employment	Sales	R&D stock	Age	Citations/R&D stock
Employment	1.0000	0.7767	0.5832	0.0001	-0.0123
Sales	0.7767	1.0000	0.5990	0.0360	-0.0125
R&D stock	0.5832	0.5990	1.0000	0.1007	-0.0121
Age	0.0001	0.0360	0.1007	1.0000	-0.0259
Citations/R&D stock	-0.0123	-0.0125	-0.0121	-0.0259	1.0000

Notes: "Employment" is in thousands; "Sales" is in 2000 millions; "R&D stock" is the discounted sum of R&D expenditures in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; observations with zero R&D stock are excluded; there are 8,758 observations; the dataset is from Hall et al. (2005) and Compustat.

Table 8 contains the correlation coefficients between employment, sales, age, citations per employee, and citations per dollar of sales for all firms. The two measures of R&D productivity are weakly negatively correlated with both measures of firm size. Firm age is weakly negatively correlated with citations per dollar of sales, but weakly positively correlated with citations per employee.

Table 8: Correlation Coefficients, All Firms

	Employment	Sales	Age	Citations/Employee	Citations/Sales
Employment	1.0000	0.7603	0.0112	-0.0416	-0.0089
Sales	0.7603	1.0000	0.0295	-0.0356	-0.0077
Age	0.0112	0.0295	1.0000	-0.0067	0.0070
Citations/Employee	-0.0416	-0.0356	-0.0067	1.0000	0.1654
Citations/Sales	-0.0089	-0.0077	0.0070	0.1654	1.0000

Notes: "Employment" is in thousands; "Sales" is in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; there are 12,742 observations; the dataset is from Hall et al. (2005) and Compustat.

Consider the R&D productivity of small versus large firms for R&D-performing firms. Define small firms as those with at most 290 employees (the median). Small firms obtained on average 1.2626 citations per dollar of R&D stock, while large firms obtained 0.5712; thus, small firms obtained on average 2.2104 times more citations per dollar of R&D stock than large firms. This is similar to the estimate obtained by Acs and Audretsch (1991b), who find that small firms contribute 2.4 times more innovations per employee than do large firms.

Consider the R&D productivity of young versus old firms for R&D-performing firms. Define young firms as those at most 18 years of age (the median). Young firms obtained on average 1.2117 citations per dollar of R&D stock, while old firms obtained 0.5344; thus, young firms obtained on average 2.2674 times more citations per dollar of R&D stock than old firms.

Consider R&D productivity jointly across the firm size and age distributions for R&D-performing firms. Divide the sample into four quadrants: young small firms, young large firms, old small firms, and old large firms. The definitions of small and young are the same as before. Table 9 contains the mean citations per dollar of R&D stock for each quadrant. Among young firms, small firms obtained on average 2.4160 times more citations per dollar of R&D stock than large firms; by contrast, among old firms, small firms are 2.0453 times more productive at R&D. Among small firms, young firms obtained on average 2.5039 times more citations per dollar of R&D stock than old firms; by contrast, among large firms, young firms are 2.1197 times more productive at R&D.

Table 9: Mean Citations per Dollar of R&D Stock

	Small	Large	Small/Large
Young	1.7535	0.7258	2.4160
Old	0.7003	0.3424	2.0453
Young/Old	2.5039	2.1197	

Notes: small firms have at most 290 employees (the median); young firms have at most 18 years of age (the median); "R&D stock" is the discounted sum of R&D expenditures in 2000 millions; "Citations" are the total number of citations received in future patent filings; observations with zero R&D stock are excluded; there are 8,758 observations; the dataset is from Hall et al. (2005) and Compustat.

To summarize, these simple correlations and comparisons suggest small firms are more innovative per dollar of R&D than large firms, and the extent to which this occurs is decreasing in firm age; and young firms are more innovative per dollar of R&D than old firms, and the extent to which this occurs is decreasing in firm size.

4.3 Regression Results

Consider the sample with R&D-performing firms, for which R&D productivity is measured using citations per dollar of R&D stock, and firm size is measured using employment, sales, and R&D stock. Since most observations have zero citations, the dependent variable used is Log((1+Citations)/R&D stock). The first citation is interpreted as the patent itself. Every regression has three independent variables: log age, log size, and log size times log age. Three OLS regressions are performed including year and 2-digit SIC industry fixed effects.[4]

Regressions of R&D productivity are run against firm size, age, and the interaction of size and age. Table 10 contains the results. In all three regressions, age has a negative effect on R&D productivity, and in two of the three cases the age coefficient is significant.[5] In all three regressions, size has a significant negative effect on R&D productivity; and the interaction of size and age has a significant positive effect on R&D productivity. Taking into account the interaction term, in all three regressions, across the entire firm size distribution, firm age has a negative effect on R&D productivity; and across the entire firm age distribution, firm size has a negative effect on R&D productivity.

4 In all reported regressions, Hausman tests reject random (versus) fixed effects.
5 In all reported regressions, the significance level is 1%.

Table 10: OLS Regressions of R&D Productivity, R&D-Performing Firms

	(1) Log((1 + Citations)/R&D stock)	(2) Log((1 + Citations)/R&D stock)	(3) Log((1 + Citations)/R&D stock)
Log(Age)	-0.0057	-0.8171*	-0.5977*
	(0.1390)	(0.1838)	(0.1392)
Log(Employment)	-0.9383*		
	(0.1032)		
Log(Employment)* Log(Age)	0.2175*		
	(0.0357)		
Log(Sales)		-0.7334*	
		(0.0951)	
Log(Sales)* Log(Age)		0.1547*	
		(0.0329)	
Log(R&D stock)			-1.0486*
			(0.0771)
Log(R&D stock)* Log(Age)			0.1318*
			(0.0273)
R-squared	0.6478	0.6486	0.7180
Observations	8,758	8,758	8,758

Notes: standard errors in parentheses; all regressions include year and 2-digit SIC industry fixed effects; * = significant at the 1% level; "Employment" is in thousands; "Sales" is in 2000 millions; "R&D stock" is the discounted sum of R&D expenditures in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; observations with zero R&D stock are excluded; the dataset is from Hall et al. (2005) and Compustat.

Consider regression (1) of Table 10, wherein employment is the measure of firm size. Taking into account the interaction term, for firms with an age in the 25th percentile (14 years of age), the elasticity of R&D productivity with respect to employment is -0.3643; for median age firms (18 years of age), the elasticity is -0.3096; and for firms with an age in the 75th percentile (21 years of age), the elasticity is -0.2761. This illustrates the (weak) extent to which the negative effect of firm size on R&D productivity is decreasing in firm age. Now consider the effect of firm age. For firms with a size in the 25th percentile (110 employees), the elasticity of

R&D productivity with respect to age is -0.4858; for median size firms (290 employees), the elasticity is -0.2749; and for firms with a size in the 75th percentile (806 employees), the elasticity is -0.0527. This shows the (considerable) extent to which the negative effect of firm age on R&D productivity is decreasing in firm size.

Consider the sample with all firms, for which R&D productivity is measured using citations per employee and per dollar of sales, and firm size is measured using employment and sales. The dependent variables used are Log((1+Citations)/Employee) and Log((1+Citations)/Sales). Four OLS regressions are performed including year and 2-digit SIC industry fixed effects. Table 11 contains the results. In all four regressions, size has a significant negative effect on R&D productivity. When firm size is measured using sales, age has a significant negative effect on R&D productivity; however, when firm size is measured using employment, age has an insignificant effect on R&D productivity. In all four regressions, the interaction of size and age has a positive effect on R&D productivity, and in three of the four cases the coefficient is significant.

Table 11: OLS Regressions of R&D Productivity, All Firms

	(1) Log((1 + Citations)/ employee)	(2) Log((1 + Citations)/ employee)	(3) Log((1 + Citations)/ sales)	(4) Log((1 + Citations)/ sales)
Log(Age)	-0.0983	-0.3873*	0.0588	-0.5338*
	(0.1021)	(0.1364)	(0.1118)	(0.1293)
Log(Employment)	-1.0402*		-1.0474*	
	(0.0648)		(0.0709)	
Log(Employment)* Log(Age)	0.0854*		0.1019*	
	(0.0224)		(0.0245)	
Log(Sales)		-0.6812*		-1.0974*
		(0.0636)		(0.0603)
Log(Sales)* Log(Age)		0.0316		0.0920*
		(0.0221)		(0.0210)
R-squared	0.8017	0.7785	0.8058	0.8371
Observations	12,742	12,742	12,742	12,742

Notes: standard errors in parentheses; all regressions include year and 2-digit SIC industry fixed effects; * = significant at the 1% level; "Employment" is in thousands; "Sales" is in 2000 millions; "Age" is in years; "Citations" are the total number of citations received in future patent filings; the dataset is from Hall et al. (2005) and Compustat.

Overall, then, the regression results are generally robust to using different measures of R&D productivity and firm size. The results broadly suggest that small firms are more innovative per dollar of R&D than large firms, and the extent to which this occurs is decreasing in firm age; and young firms are more innovative per dollar of R&D than old firms, and the extent to which this occurs is decreasing in firm size.

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