R&D Intensity and Firm Size Revisited

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Abstract

Even if technology and innovations are the engines of growth, the US's effort to create an environment that fosters innovation has not been very successful. Moreover, data shows that the US has been losing its competitive edge in the global race for innovation. Between 1999 and 2007, US's share of global R&D has fallen from 39% to 33% while China's R&D share has increased and is now second only to that to Japan. Current US policies intended to encourage innovation - tax credit/subsidies, patent laws, etc. - do not recognize the difference in funding ability between large firms and small ones. As a result, these policies benefit larger firms and sometimes discourage innovations coming from small entrepreneurs. One of the reasons why the US does not have R&D policies dependent on size might be found in the lack of empirical evidence proving the existence of a systematic relationship between firm size and R&D intensity. In this paper, I closely examine the relationship between the size of a firm and its efforts for innovation, measured in R&D expenditure. I use the US firm level data (Compustat), which provides empirical evidence in contrast with those historical studies that showed R&D intensity to be constant across all firm sizes. By looking at the way in which small firms are funded through venture capital market, this study shows that smaller firms are a very important driving force of the US innovation, and therefore, it argues in favor of size dependent R&D tax credit programs and patent policies. Such measures would lessen the burden on small firms thus helping the US economy to sustain growth and create more jobs.

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1 Introduction

Joseph Schumpeter, one of the first scholars to emphasize the importance of innovation for economic growth, believed that new ventures by individual entrepreneurs are the major source of innovation. In his later work, however, he radically changed his thesis and argued that large firms are, in fact, the main source of innovation. Since then, many scholars have tried to resolve the issue of whether there is a significant relationship between firm size and their innovative effort. In most cases the answer has been negative.

Most of these studies have specifically looked at whether large firms spend a higher fraction of their revenue in Research and Development (R&D) activities than small firms do. The evidence, according to studies using 1970s firm level data, suggested that R&D expenditure increased proportionally to the size of the firm, measured by total revenue. These studies showed that R&D intensity, measured as the percentage of the firm's total revenue invested in R&D, does not increase with firm size, disproving Schumpeter's hypothesis that the large firms' innovative efforts are far more significant than those of smaller firms. Among these studies there are Bound et al. (1984) and Cohen et al. (1987). In addition, numerous economic models of innovation have been built assuming this stylized fact, including that by Klette and Kortum (2004). Moreover, given the wide acceptance of this idea, U.S. policies have been designed paying no regard to the size of the firms, failing to recognize the difficulties small start-up firms face.

However, Akcigit's recent study (2009) - which used the firm level data from 1980 to 2005 - found that R&D intensity is negatively related to firm size, and suggested that small firms are characterized by a higher R&D intensity when compared to large firms. Such a find is astounding, for the data set used in Akcigit (2009) is the same Compustat data used in Bound et al. (1984), only updated to the year 2005. The two papers, however, draw opposing conclusions on the relationship between R&D intensity and firm size. Why is there such a drastic difference between these two sets of papers in describing firms R&D behavior? Did firms change over time the way they invest in R&D? Or does the larger, more recent data show a more accurate picture of the relationship between firm size and R&D? In this paper, I carefully examine the source data, Compustat, in order to determine whether such discrepancies were caused by fundamental changes in firms behavior, or by a structural change in dataset.

Analysis shows that a new type of firm appears in the data starting from the 1980s: firms with nearly zero revenue, spending significant sums in R&D. Naturally, they influence significantly the relationship between R&D intensity and firm size. Thus, I explored the possible link between the venture capital market and the appearance of these types of firms. Having identified the new type of firms, I conducted various regression analyses, which showed that there is a systematic relationship between R&D and firm size. In fact, small firms play a crucial role in promoting innovation. A better understanding of the the relationship between firm size and R&D intensity would help identify what type of firms innovate more heavily, thus helping devising R&D related regulations aimed at promoting and nurturing innovation in a more effective way.

In section 2, I will begin by reviewing U.S. current policies designed to foster innovation; in section 3, I will summarize the studies by Bound et al and Akcigit; in sections 4 and 5, I will present my observation from the same data source employed by the two aforementioned studies.

2 Policy Evaluation

It is common knowledge that technology and innovations are the engines of growth. This fact is, perhaps, best demonstrated by the invention of computer, a tool that increased overall productivity across all different sectors of the economy, and spurred additional innovations in software and other related technologies, ultimately improving the quality of life. According to USPTO and the U.S. Department of Commerce, "technological innovation is linked to three-quarters of the Nation's post-WWII growth rate." Similarly, Boucher and Abdala (1999) reported that over two-thirds of the average annual increase in per capita wealth of the United States is attributable to technological change as it becomes embodied in new products, new capital equipment and new production methods.

Despite the abundant evidence of the critical role innovation plays in promoting growth and prosperity, U.S.'s efforts to create an environment that fosters innovation have not been very successful in recent years. Data shows that the U.S. has been losing its competitive edge in the global race for innovation. Between 1999 and 2007, the U.S.'s share of global R&D has fallen from 39% to 33%, while China's R&D share has increased, and it now has the world's second largest share of R&D, second only to Japan. The current administration recognizes the need to improve the competitiveness of U.S. innovation and provided new strategies that included an increase in basic R&D funding. However, before discussing the current initiatives of reform in innovation policies, let's take a closer look at the past governments effort toward the same goal.

One of the ways in which the government can promote innovation is by encouraging private R&D investment, through R&D tax credit and/or subsidy programs. The U.S. began a R&D tax credit program in 1981 and provided a temporary tax credit for qualified business research expenses. This R&D tax credit program put the U.S. in the first place for the most generous tax treatment of R&D expenses among all OECD countries. Although the R&D tax credit had been very effective in boosting innovation and competitiveness in 1980s, it has lost its effectiveness, for these policies have never achieved permanent status. In fact, since 1981, the R&D tax credit policy has been extended 11 times, and has expired four times. Due to the temporary status of these measures, other countries have surpassed the U.S. in the race for innovation. By 2004, the U.S. ranked 17^{th} in the list of countries with the most generous R&D tax credit. The unpredictable - and thus unreliable - nature of the current tax credit policy discourages firms that conduct heavy R&D from planning future projects. A more stable policy would be especially helpful for small firms that cannot self finance R&D investments, whereas larger firms can buffer the periods in which they do not receive tax credits.

Moreover, the current U.S. innovation policies do not recognize the different challenges small start-up firms face when compared to large firms. A growing number of countries recognize the importance of encouraging small business entrepreneurs by implementing R&D tax provisions that favor small firms. In the past two years, Australia, Hungary, Norway, Portugal, Spain and the United Kingdom significantly improved the attractiveness of their R&D tax systems using size dependent R&D programs.

In addition to R&D tax credit, the U.S. government provides a large amount of funds in R&D; between 1941 and 2000, the U.S. government spent $2.7 trillion in R&D. The federally funded R&D expenditure constitutes more than 50% of the total R&D expenditure in the U.S.. However, the majority of federally funded R&D activities took place in laboratories owned by the Department of Defense and Energy, whose primary goal is to design and test nuclear weapons. Shifting composition of the federal funded R&D expenditure more toward research universities - that often collaborate with small firms - may foster innovation, create new jobs, and promote higher rate of growth.

Another way in which the government can induce innovation is to provide monopoly rights to the inventor through intellectual property rights. While in theory, patent rights give small innovators higher incentive to innovate, in practice, the efficacy of patent rights has not been proven. According to the available studies exploring the relationship between patent systems and innovation, it is unclear whether such regulations result in an increase in innovation (Hall 2002).

In fact, patent protection, rather than inducing innovative activities, often may increase the number of litigations. Patent owners usually try to discourage other innovators from inventing similar products. This occurs when the validity and the boundaries of intellectual property rights are unclear. In addition, many lawsuits are initiated by "patent trolls:" people who obtain broad patents not for the purpose of innovation, but solely to ensnare real innovators, who might inadvertently cross the boundaries of the trolls' patent (Bessen and Meurer 2008). Due to the high cost and time consuming nature of litigation, smaller firms are at a great disadvantage, causing some to argue that patent protection actually discourages innovation. Therefore, reforms in patent protection and enforcement that is not biased toward larger corporations may have a positive effect on welfare.

Starting in the late 1970s and the early 1980s, the U.S. has experienced a large success of the venture capital industry. Venture capital is an equity or equity-linked investment in young companies with high potential. These venture capital investments gave rise to high profile companies such as Digital Equipment Corporation, Apple Inc. and Genentech. The access to venture capital investment spurred innovation by enabling small start-up companies to conduct R&D and to obtain patents. However, since the bursting of the internet bubble in early 2000, the industry has not been able to revive its old glories, thus failing to promote the growth of small companies. Tax benefits, such as more competitive capital gains tax rate for I.P.O. investors and tax incentives for clean tech companies may encourage higher activities in the venture capital market industry.

By looking at the way small firms are funded through venture capital market, this study shows that smaller firms are a very important driving force of the U.S. innovation, and therefore, it argues in favor of size dependent R&D tax credit programs and patent policies. Such measures would lessen the burden on small firms, helping the U.S. economy to sustain growth and create more jobs.

3 Examining Stylized Fact

This section presents two empirical studies that examine the relationship between R&D intensity and firm size, both of which use the same source of firm level data, but draw opposing conclusions. The following sections will include a brief explanation of the data used in each study, the specification for their regressions, and their findings.

3.1 R&D intensity is independent of firm size

Early empirical studies have been unable to identify any evidence of a systematic relationship between firm size and the elasticity of R&D, regardless of the type of industry. And yet, this invalid hypothesis - that R&D varies proportionally with size, across the entire distribution of firm size - is still currently believed as true.

Bound et al. (1984) - one of the studies we just referred to - used the Standard and Poor's Compustat data for all publicly traded companies in the U.S. manufacturing industry existing in 1976; this dataset also contained time series information on the same firms for 2 years before and after 1976. Foreign owned companies were excluded from the study, and all subsidiaries were identified and combined into their parent corporation. This cross sectional data includes 2,595 firms, with 1,492 reporting positive R&D in 1976.

Employing the following specification for the OLS regression,

$$\ln R = \alpha + \beta \ln S + \varepsilon \tag{1}$$

(where R represents R&D expenditure and S represents sales revenue), Bound et al. found that the coefficient of firm size on R&D is close to 1 (0.965, to be precise), thus implying that, regardless of their size, each firm allocates a constant proportion of their revenue to R&D activities. Other studies that used various firm level data - including FTC's Line of Business program by Cohen et al (1987) - confirmed this pattern. Given the wide consensus, this empirical result has been used in numerous economic models, to the present day. For instance, Klette and Kortum (2004) constructs a model for innovating firms consistent with the fact that R&D increases proportionally with firm size.

3.2 R&D intensity is negatively related to firm size

Unlike Bound et al., Akcigit (2009) presents a new pattern in a firm's R&D behavior with respect to its size. Akcigit uses more recent Compustat data - ranging from 1980 to 2005 - in order to examine the relationship between a firm's spending on R&D and its size. Instead of looking at the linear relationship between R&D expenditure and revenue, he examines the linear relationship between R&D intensity (measured as the percentage of the firm's total revenue invested in R&D) and firm size.

Akcigit's specification is as follows:

$$\ln(R/S) = \alpha' + \beta' \ln S + \varepsilon \tag{2}$$

Although this specification appears to be different from Bound et al, a little bit of algebra will show that $\beta = \beta' + 1$. Taking into consideration time-varying industry effects, Akcigit found that the coefficient of the firm size on R&D intensity is -0.265. This finding suggests that as firms increase in size, they allocate a smaller percentage of their revenue to R&D investments. This result proves Schumpeter's earlier belief that small firms innovate more. However, upon discovering this new pattern - contrary to those identified by earlier studies - Akcigit does not attempt an explanation of the reasons for such changes over time. In the next section, I will examine the data and methodologies used in the two studies, and reconcile the differences by looking at the way in which small firms are funded through the venture capital market.

4 Empirical Analysis

If Akcigit's finding about the pattern of firms' innovative behavior were indeed true, it would render obsolete all those theories of innovation based on the belief that R&D intensity and firm size are independent. Furthermore, future theories should reflect the newly discovered fact that small firms are more innovative than larger firms. Before accepting the new pattern within the data as a fact, one must exercise caution, and carefully examine the datas structure in order verify the validity of the new findings. In this section, I will provide a detailed description of the Compustat, pointing out the advantages and disadvantages of using this particular data set. Subsequently, I will document the changes in firms' R&D behavior over time.

4.1 Data

Standard & Poor's Compustat data contains firm level annual and quarterly data for all publicly traded companies in the U.S., dating back to 1950. It includes items reported by companies in standard financial reports, such as income statement, balance sheets and cash flow statements. Although it is the most detailed firm level data publicly available, it has its flaws.

As it only includes firms that are publicly traded, the observations may not reflect the firms in their infant stage, when innovation may be the most active. It also includes firms over a certain size, thus it reflects firms that are fairly successful. This constitutes a potential bias when using this data set for firm size analyses. However, the firm size distribution in Figure 1 indicates that this potential bias may have weakened over time. The size distribution shows wider range of firm size in the data over time, as well as a thickening of the left tail. This suggests that not only does the data include larger sample with wider range in size, but it also includes more small firms. In addition, the median firm size has significantly decreased over time. (see Table 1).

One of the advantages of using Compustat data, however, is that information about the individual firm's patent, obtained by USPTO, can be added by using the NBER's concordance data. The specific variable of interest is the number of innovations the firm possesses; however, the NBER Patent Data provides either the number of patents the firm applied for or those granted to the firm. For the purposes of this paper, I will be using the total number of patents that the company requested to USPTO as a proxy for the number of successful innovation resulting from R&D, and leading to an increase in the value of the firm. The details about how USPTO data and Compustat were matched for each firm can be found in Hall et al (2001). In short, the final patent data set to be added onto Compustat includes all utility patents between 1963 and 2002. Due to the time consuming nature of the matching process, the current patent data can only be matched to the firms that existed in 1989, excluding the firms that entered into Compustat after 1989.

In addition, I will use venture capital investment data from National Venture Capital Association Yearbook (from 1980 to 2009). However, as the categorization of the industries is different from that of Standard Industrial Code (SIC), I used the concordance information linking NVCA industries to SIC, provided by Professor Dushnitsky from London Business School.

Being aware of the potential bias this data may still contain, I use the annual Compustat data from 1950 to 2009 in order to examine the firm's behavioral changes in innovation over time. Moreover, following Bound et al. and Akcigit's sample selection, I only include domestic manufacturing firms from the sample.

4.2 OLS Regression Analysis

The results from Bound et al. come from 1976 cross-sectional data analysis. In order to ensure that their results were not the product of an abnormal activity in that particular year, I conducted the same cross-sectional regression analyses for each year between 1950-2009, using the specification found in Bound et al.,

$$\ln R = \alpha + \beta \ln S + \varepsilon \tag{3}$$

In doing so, I confirmed that, in the 1970s, the slope coefficients were close to 1, implying that firms' R&D expenditure increased proportionally with size. However, over time, the slope coefficients gradually decreased to a figure lower than 0.3 in 2000s, thus suggesting that small firms spent a higher fraction of their revenue for research and development. The results of these regressions are presented in Figure 2; in order to avoid redundancy, I present only the results for every 10 year period, starting from 1976, the year in which Bound et al's study was conducted.

The gradual decrease in slope coefficient confirms the results from both studies; while slope coefficient was close to 1 in 1976 - consistently with the results obtained by Bound et al - in 2006, β decreased by more than 50% - thus confirming Akcigits observations. However, I noticed that this decrease in slope coefficient is almost entirely driven by the appearance of a new type of company: firms with nearly zero revenue, spending significant sums in R&D. From Figure 2, one can see that the decrease in slope coefficient is largely due to the observations noted on the bottom left corner of the scatterplots. Moreover, starting in 1985, the number of firms with nearly zero revenue and positive R&D expenditure increases significantly. Thus, I repeated the regression analyses, excluding the firms whose total R&D expenditure is greater than their total revenue.

As shown in Figure 3, after removing the small firms that could have affected the sharp decrease in slope coefficient, I observed a less than 10% decrease in β between 1976 and 2006, instead of the 50% decrease obtained when including the small firms. As these changes in slope coefficients can be driven by a specific industry, I conducted another set of regressions, which included the dummy variables for industry, categorized by the 3-digit SIC code. The results of these regressions are shown in Table 2 and 3. Even after including the industry dummies, the results of the regression still shows the gradual and significant decrease in the slope coefficient for all firms, from 0.819 in 1976, to 0.275 in 2006. When excluding the firms that spent in R&D more than they collected in revenue, the slope coefficient changes from 0.953 in 1976, to 0.857 in 2006. In short, including the industry dummies does not change the regression results.

These results raise the issue of identifying the firms belonging to this new type. More importantly, one must establish whether Akcigit's results have been driven by changes in IPO market - which allowed the entry of firms that do not generate much revenue, but spend large sums in R&D -, or by changes in the way firms invest in R&D over time. Furthermore, the importance these small firms have in determining the relationship between R&D intensity and firm size demands a closer examination of their identity. They may be firms that specialize in R&D, or firms with an ability to finance themselves without generating much revenue. Finding out how they were included in the Compustat data set will provide better understanding of their innovative behavior.

4.2.1 Examination of Data Entries

From these series of regressions, it seems that the slope coefficients are very sensitive to the firms whose R&D expenditure is greater than the revenue. It is puzzling how firms with almost no revenue can spend significant amount of money on R&D, and how they came to meet the criteria to be accepted into IPO. Therefore, I examined their individual records, in order to determine whether they entered the data set by mistake, and to examine the actual significance of such entries. First, I divided all firms into 3 categories. Firms that spend less on R&D than their revenue are categorized as Firmtype 1; firms that collect a positive revenue, but spend more on R&D than their revenue are categorized as Firmtype 2; firms that collect zero to negative revenue, but sustain positive R&D expenditure are categorized as Firmtype 3.

Even if the log regression results presented in Figure 2 include both firmtype 2 and firmtype 3, I conducted the regressions in 2 different stages, in order to evaluate the effects of each firmtype separately. I first conducted the log regression according to the specifications found in Bound et al.. Due to the logarithmic functions, without treatments, the firmtype 3 - whose revenue is 0 - was not reflected in the results. In the results of this regression, I observed that the slope coefficient shifts from 0.84 in 1976 to 0.49 in 2006. Afterwards, I conducted a similar regression by adding a miniscule amount ($1) to the revenue, in order to observe the effects of Firmtype 3 entries. As one can see from Figure 2, the firmtype 3 entries amplify the percent change in regression slope; the slope coefficient drops from near 1 in 1976 to .3 in 2006.

In order to show the compositional changes in firmtypes over time, I compiled Table 3, which shows the distribution of these 3 types of firms in the data, from 1960 to 2009. Firmtypes 2 and 3 enter the data set in the late 1960s, and their presence significantly increases in 1980s. In the 2000s, firms belonging to firmtype 2 or firmtype 3 account for approximately 15% of total number of firms. (refer to Table 4)

A thorough investigation of individual records did not provide any evidence that the entries belonging to firmtype 2 and 3 were erroneous. In addition to the transaction records, I also conducted some background research on the companies with a higher R&D expenditure than their total revenue. Most of these firms belonging to firmtype 2 or 3 specialize in R&D, and their R&D pattern persists in the data for over 10 years, as they consistently report a revenue stream lower than their R&D expenditure.

Even if the number of firms belonging to firmype 2 and 3 increased in number, the total R&D expenditure contributed by these firms accounts only for about 3% of the total R&D in 2000s. Although these data entries seem to have little importance in terms of the percentage of total R&D expenditure, regardless of the industry, the growing number of these firms alters significantly the results of the regression. This raises the question of whether observing the firms that are spending more than they earn is a consequence of the decision to use a firm's total revenue as the measure of a firm's size. Thus, in the next section, I will explore other variables that could replace revenue as the measure of a firms size.

4.2.2 Alternative measure of Size that is robust to Small firm behavior

If the firms that belong to firmtype 2 and 3 are those who specialize in product research and development, then those firms may not necessarily generate revenue. Instead, they may hold some intangible assets or some other form of capital that gives them a significant value capable of attracting investors willing to provide resources for their R&D. These values could be reflected by the amount of intangible assets the company owns (such as patents), or by the stock price (or the market value, or book value) of the firm, calculated on the potential value of their innovation. Numerous firms in the pharmaceutical and medical research industry would not generate revenue until the effectiveness of their research is proven successful. However, they have investors who believe in the potential of the final result, and such belief enables them to conduct a very costly research, financed by the investors. Furthermore, the presence or the size of the firm in the industry would most likely be determined by these alternate measures, which quantify the firm's potential rather than the revenue that they generate. In pharmaceutical industry, for example, the number of patents that a firm owns is used as a measure of profitability of the firm.

However, as previously mentioned, the patent information in this data set only applies to those firms that existed in 1989. Therefore, the value of inventions from newer - thus smaller - firms created after 1989 cannot be measure by the number of patents. Also, 25% of patent information is missing from the sample, as shown in Table 5. Therefore, even though the number of patents held by companies may be a better measure of their potential value, given that this particular data set contains incomplete information, such measure would provide biased results.

As an alternative measure of firm's size, I calculated the market value by multiplying the current market value of company's stock by the total number of shares outstanding. However, as one of the variables has many missing observations, we can provide market value only for 78% of the data (Table 5). In addition, although both closing price and book value were recorded by Compustat, about 22% of the sample is missing the closing price while book value is recorded 95% of the time. Thus, I chose the book value to replace total revenue as an indicator of firm size, and I conducted a simple OLS regression. The results are presented in Table 6; the slope coefficient gradually decreased from 0.91 in 1976 to 0.84 in 2006. The changes in the coefficient is a lot less dramatic than when using revenue as a size variable; nonetheless, it confirms that over time, smaller firms became more R&D intensive.

Another measure of size commonly used in economic studies is the number of employees a firm has. While Compustat generally reports this information, 10% of the sample is missing it. In spite of this, I decided to conduct a regression using the number of employees as a size variable. As presented in the Table 6, the coefficient of the number of employee decreased from 0.95 in 1976 to 0.76 in 2006, consistently with the previous results. However, one cannot be absolutely certain that the decrease in the coefficients - even when using variables other than revenue - is caused by small firms. Thus, in order to check for robustness, I conducted another set of regression excluding the firms whose revenue is less than their R&D expenditure. As shown in Table 7, when using the book value as a parameter, the coefficient stayed almost constant throughout the entire time period, while the coefficient decreased only by 8% when using the number of employee as an indicator (as opposed to the 20% decrease previously observed in Table 6). These results indicate that neither the book value nor the number of employees are robust to the presence of companies belonging to firmtype 2.

Other possible alternatives to revenue as a measure of a firm's size are total assets and the capital (measured in plant, property or equipment) owned by a company. As both of these variables are recorded more than 98% of the times, I conducted two regressions using each of these variables as a replacement for the revenue. When using capital as an indicator of firm size, the slope coefficient sharply decreased from 0.81, in 1976, to 0.55 in 2006. The fact that the coefficient from the second regression - excluding the small firms - exhibited only a small decrease (from 0.82 to 0.2) shows that this measure is once again sensitive to the presence of firms belonging to firmtype 2 and firmtype 3. The result from the regression that used the total asset as a size variable, displayed similar results as previously mentioned regressions, providing no evidence of robustness.

In summary, regardless of the indicator chosen to represent a measure of a firm's size, the regressions that included all firms showed general decrease in slope coefficients, while those that excluded small firms resulted in very little change in slope coefficient. This indicates that none of these variables are robust to those firms with higher R&D expenditure than revenue. Since my search for other measures of size - capable of being unaffected by firms belonging to firmtype 2 and firmtype 3 - has proven unfruitful so far, I was unable to provide a more accurate description of the relationship between firm size and innovation. Thus, I will continue to search for patterns or characteristics of small firms. In the next section, I will take a look at the distribution of small firms across industries.

4.2.3 Industry Specificity

We have previously observed how - regardless of the variables chosen to represent firm size - the pattern in firms' innovation with respect to size has gone from having no significant relation, to displaying a strong negative correlation, due to the entry of new types of firms that heavily specialize in R&D. Thus, it is imperative to identify those firms and determine whether they are relevant for studying the pattern of innovation. What type of firms can spend more on research and development than they collect in revenue? How would they be able to sustain growth and/or survive for a long period of time in the market? Typically, a start-up company is born around a single, innovative idea. Someone who sees the potential of the innovation would then provide financial support to the company, so that it can start materializing the idea and return profit in the form of commercial products, patents etc. On a larger scale, venture capital firms would specialize in evaluating the net and future worth of start-up companies, and invest substantial amount of funds in their R&D. As venture capitalists look for high return on their investment, they generally prefer companies that deal with innovative technology and display a potential for rapid growth. As a result, they tend to invest densely in high technology industries, such as electronic, medical or data-processing technology. Thus, it is reasonable to conjecture that these new types of firms may be concentrated in specific industries.

Therefore, I examined the distribution of these 3 types of firms by industry, defined according to the 3 digit Standard Industrial Classification (SIC) codes, between 1980 and 2009. The results are presented in Table 8. The time period is chosen so that the percentage of firms belonging to firmtypes 2 and 3 are not misrepresented by the overwhelming dominance of firmtype 1, typical of the years before 1980. In Table 8, the highlighted items indicate industries in which the percentage of firmtype 2 and firmtype 3 constitute more than 5%, and have ample number of observations each year from 1980 to 2009. Among these industries there are: Drug industry (SIC code 283); Computer and Office Equipment industry (SIC code 357); Electronic and Other Electric Equipment industry (SIC code 36-); Laboratory Apparatus industry (SIC code 382); and Surgical, Medical and Dental Instrument industry (SIC code 384). These industries coincide with those industries in which venture capitalists have a strong interest.

So far, the data showed that the firms belonging to firmtypes 2 and 3 appear in the data with significant increase in number in the 1980s, and are densely concentrated in pharmaceutical and information technology industries. In Figure 4, I present the annual R&D expenditure of those firms included in firmtype 2 and firmtype 3, organized according to the type of industry they belong to, in an effort to discover any fluctuations that may be related to activities in the Venture Capital market. Before analyzing the data, I will provide a broad background information on trends in venture capital market.

4.2.4 Venture Capital Investment Market

Although the first venture capital firms were born after World War II, it was not until the late 1970s and early 1980s that venture capital investment companies experienced great success. This was due to the US Labor Department's relaxation of certain restrictions on how corporate pension funds could be employed. During this period, the number of venture capital investment firms multiplied, reaching almost 650. These venture capitalists gave birth to Apple Inc, Digital Equipment Corporation and Genentech. However, toward the end of 1980s, the higher level of competition, domestically and internationally, as well as the stock market crash of 1987, slowed down the market activities, and the venture capital industry experienced low returns on their investments. The cooling of venture capital market continued until the major shakeout of venture capital managers of the early 1990s. Then, in 1995, the second boom period in venture capital began, with surging interest in Internet and other computer technology firms. The expansion lasted until the burst of the internet bubble, which led to the Nasdaq crash of 2000; since then, there has been a steady slowdown, until 2005. The internet-driven environment helped revive the venture capital market through 2007, but the recovery has not been able to bring back the level of success enjoyed in the mid-1990s.

In Figure 4, the major events that caused the boom and bust cycle of the venture capital industry is indicated with vertical lines. In addition, the R&D expenditure of firmtype 2 and firmtype 3 followed a trend similar to that of venture capital market activities. This is not surprising, for the firms whose R&D expenditure is higher than their revenue are very likely to be venture backed start-up companies. The number of firms with higher R&D expenditure than their revenue increased drastically in the 1980s, and their R&D expenditure increased at the highest rate during the early 1980s, following the first boom period of venture capital market. With the only exception of the Drug industry, a general decline in R&D expenditure begins between 1985 and 1987. During the same period, the venture capital market cooled down, due to the increase in competition and to the stock market crash. Starting in 1990, the R&D expenditure of firmtypes 2 and 3 sharply rose, and continued to rise during the period of the managers shakeouts and the second boom of the venture capital market. Furthermore, the R&D expenditure shows significant decrease in 2000, when the internet bubble burst. Although R&D expenditure shows a slight increase in 2005, the general trend seems to indicate that these firms spend less in R&D toward 2009. In summary, the trend in R&D expenditure of firmtype 2 closely follows the trend in venture capital market. Thus, it is very likely that firmtype 2 are start-up companies.

By the evidence provided so far, the emergence and boom/bust cycle of the venture capital market seem to have a significant impact on R&D expenditure of small firms, which in turn, affects the overall relationship between R&D intensity and the size of the firm. Thus, I modified the regression in order to study the magnitude of these effects. However, since venture capital market has a very selective interest in specific industries, I conducted a separate regression for a selected number of industries related to biotechnology and information technologies.

4.3 Regression with Instrumental Variable

In order to investigate the relationship between firm's innovative effort and firm size, the following regression is estimated using OLS for each industry mentioned in the previous section.

$$\ln R_{it} = \alpha + \beta \ln S_{it} + \gamma \ln V_{it} + \varepsilon_{it} \tag{4}$$

where R indicates a firm's R&D expenditure, S indicates a firm's size, V represents venture capital investment for each industry, i, over time, t, with firm fixed effects. When resorting to the total asset variable as a parameter to indicate firm size, the regression showed more stability and robustness in scatter plot with respect to firmtypes 2 and 3. Thus, I used this variable in this regression.

R&D expenditure may depend on how large the company becomes; in the case of small start-up companies, it may also depend on how much venture capital investment flows into the firm. The results of the OLS regression, using the panel data, are presented in Table 9. The numbers in parenthesis indicate that the value is not statistically significant. As expected, for each industry, the slope coefficient corresponding to the size variable is less than 1. This indicates that the larger the company becomes, the smaller the share of R&D expenditure becomes. Moreover, with the exception of the computer industry, the slope coefficient of venture capital investment for each industry has a positive effect on R&D expenditure. However, this specification may contain omitted variable bias.

First, let's take a look at the size variable and R&D expenditure. As a firm becomes more productive, it may accumulate more assets, while its innovative activities increase. Therefore, changes in a firm's specific characteristics can create a higher correlation between the dependent and independent variables. Similarly, there could be other firm-specific factors that affect venture capital investment flow into the firm, as well as R&D expenditure. One way to fix this problem is to include the firm's fixed effects into the above specification. The results of the regression with firm's fixed effects are presented in Table 10. Adding the fixed effects slightly decreases the slope coefficients of the size variable and venture capital investment, with the exception of the drug industry, while its explanatory power remains unchanged.

In addition to the firm's fixed effects, there could be some other factors that affect both the venture capital investment flow into the industry and the R&D expenditure. For example, a change in patent laws intended to encourage innovation in a specific industry may induce more venture capital investments to flow into that industry, while it also induces more in-housing R&D, due to higher propensity to patent. Therefore, the variation in V_{it} may be correlated with the disturbance, ε_{it}, and simply regressing the venture capital investment on R&D expenditure could yield biased estimates of γ. Thus, I use an instrument variable in order to avoid the potential biases in my estimate of the strength of venture capital investment.

The instrument variable must be correlated with the venture capital investment in industry i, while it must be independent from the error term, ε_{it}. The amount of venture capital investment in an industry would depend on overall movement of venture capital market, as well as on the industry specific factors. Therefore, in 2 industries, for example, pharmaceutical and computer, these variables would have the following relationship:

$$V_{pharma,t} = \theta V_t + \epsilon_{pharma,t} \quad (5)$$

$$V_{computer,t} = \theta' V_t + \epsilon_{computer,t} \quad (6)$$

$V_{computer,t}$ is correlated with $V_{pharma,t}$ through the general shock in venture capital market, while it does not affect the disturbance in pharmaceutical industry. Therefore, I will use $V_{j,t}$ as an instrumental variable for the regression analysis for industry i. The results from IV regression with firm's fixed effects are presented in Table 11.

Overall, all coefficients of size variables are significantly less than 1, indicating that small firms are more R&D intensive. Moreover, the coefficients of industry specific venture capital investments have positive effects on R&D expenditure, although the magnitude varies between industries, and some of the coefficients are not statistically significant.

5 Conclusion

This paper examines the U.S. firm level data in an effort to reconcile two opposing stylized facts about R&D intensity and firm size, stemming from the same data set. In 1970s - when the venture capital investment market was still at its infant stage - small start-up companies did not have the means to conduct costly research and development. Therefore, most of the innovation in the U.S. was due to large companies with the ability to conduct in-house R&D. However, starting from the 1980s, because of the success of the venture capital investment market, start-up companies were able to conduct R&D even before they started generating any revenue. Evidently, this challenges the common belief that R&D intensity does not vary across firms of different size. In fact, firms of different sizes face distinct problems, and perhaps should be treated differently. Small firms may be more innovative than large firms, but they lack the funds to turn their ideas into profit; as a result, these firms are not able to become successful enough to be publicly traded. However, the development of the venture capital investment market enabled these firms to enter into the market, allowing them to grow.

The results shown in this paper suggest that small firms are more R&D intensive. Therefore, in order to increase innovation - and thus to promote economic growth - policy makers must consider size dependent R&D tax credit programs, similar to those implemented by the U.K.. Also, patent laws should be reformed, so as to prevent large companies from using the patent system to create entry barriers, discouraging the innovations by small inventors. More stable R&D tax credits and subsidy programs, redistribution of federal funding in R&D, changes in patent policies in order to remove the barrier for small innovative companies , and less strict financial statement requirements for start-up companies would help increase the much needed innovative activities in the U.S., thus sustaining growth and job creation in the long term.

Unfortunately, the Compustat data does not include all those small firms that were unable to go public. As a result, the potential effects of additional small firms have been overlooked in this study. In the future, I hope to secure access to National Science Foundation (NSF)'s R&D survey, which contains all the firms in the U.S., and could provide stronger empirical evidence of the negative relationship between R&D intensity and firm size.

Subsequently, I plan on developing a theoretic model capable of quantifying the barriers to entry small firms must face, and estimating the welfare effect of lowering such barriers through the implementation of size dependent innovation policies. Such a model would be very useful to policy makers in re-evaluating current innovation policies that fail to acknowledge the importance of size in determining firms innovation behavior.

6 Appendix: Figures and Tables

Figure 1: Firm Size Distribution

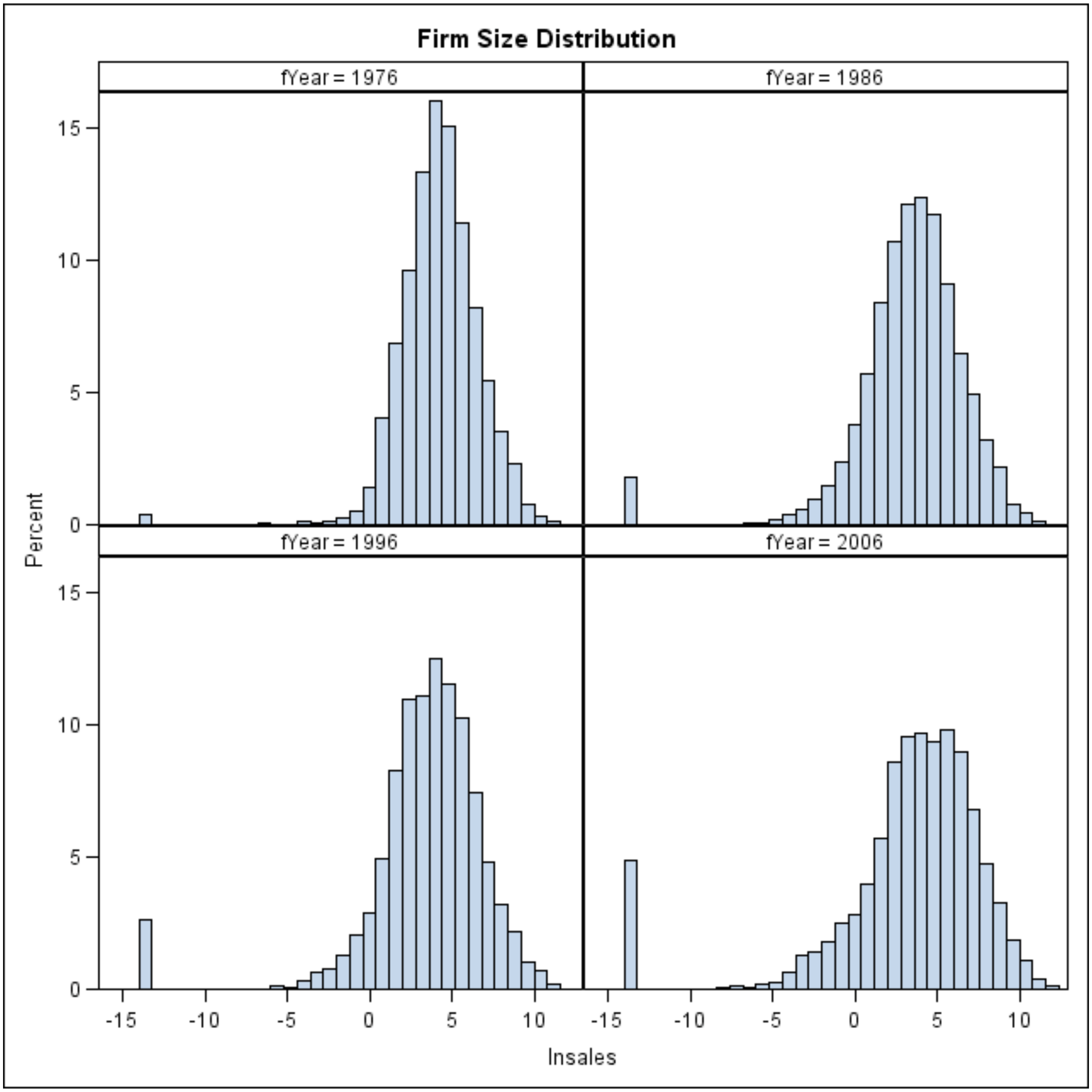

Figure 2: OLS Regression

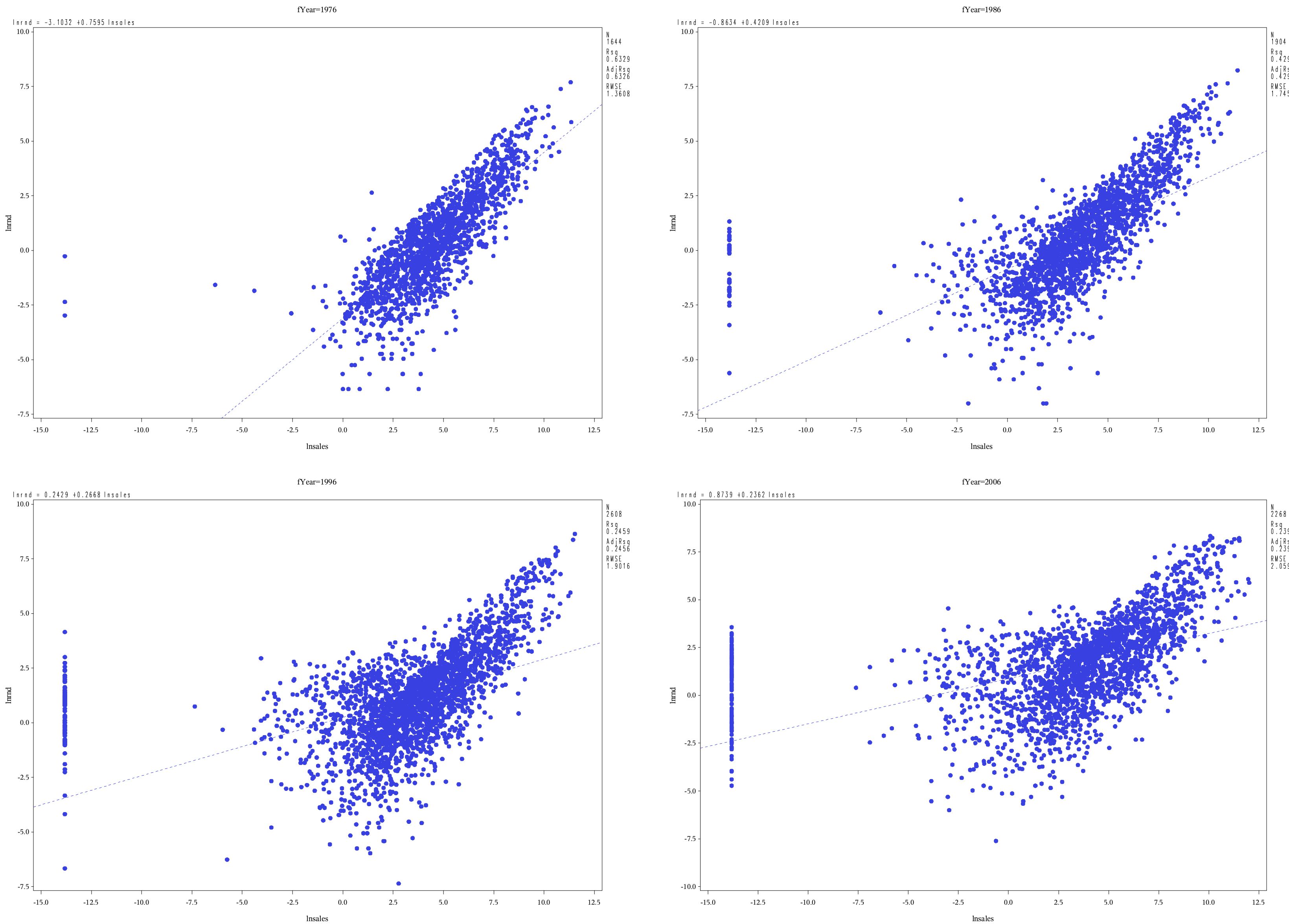

Figure 3: OLS Regression with Firmtype 1 only

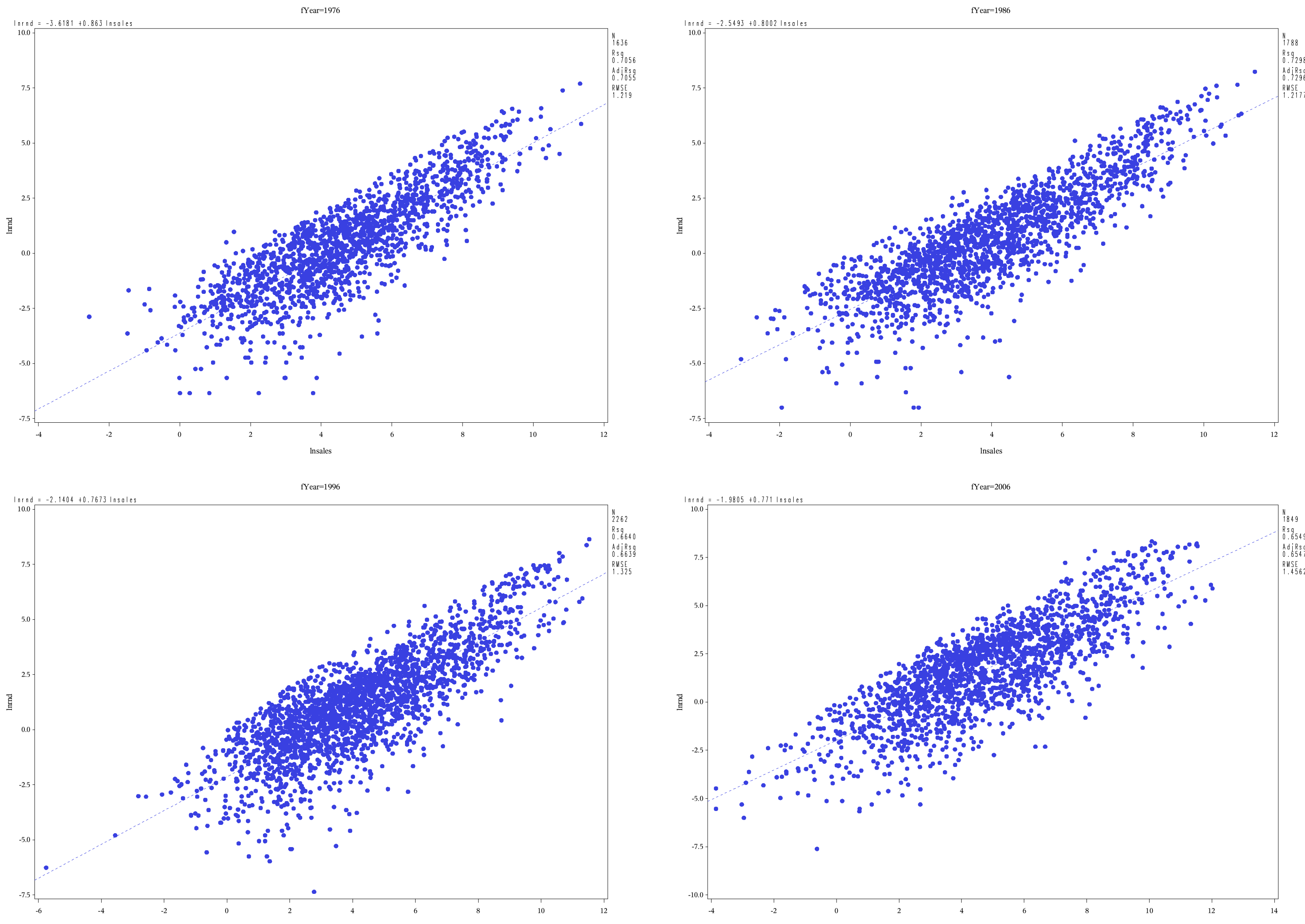

Figure 4: R&D Expenditure for Firmtypes 2 and 3 by Select Industry

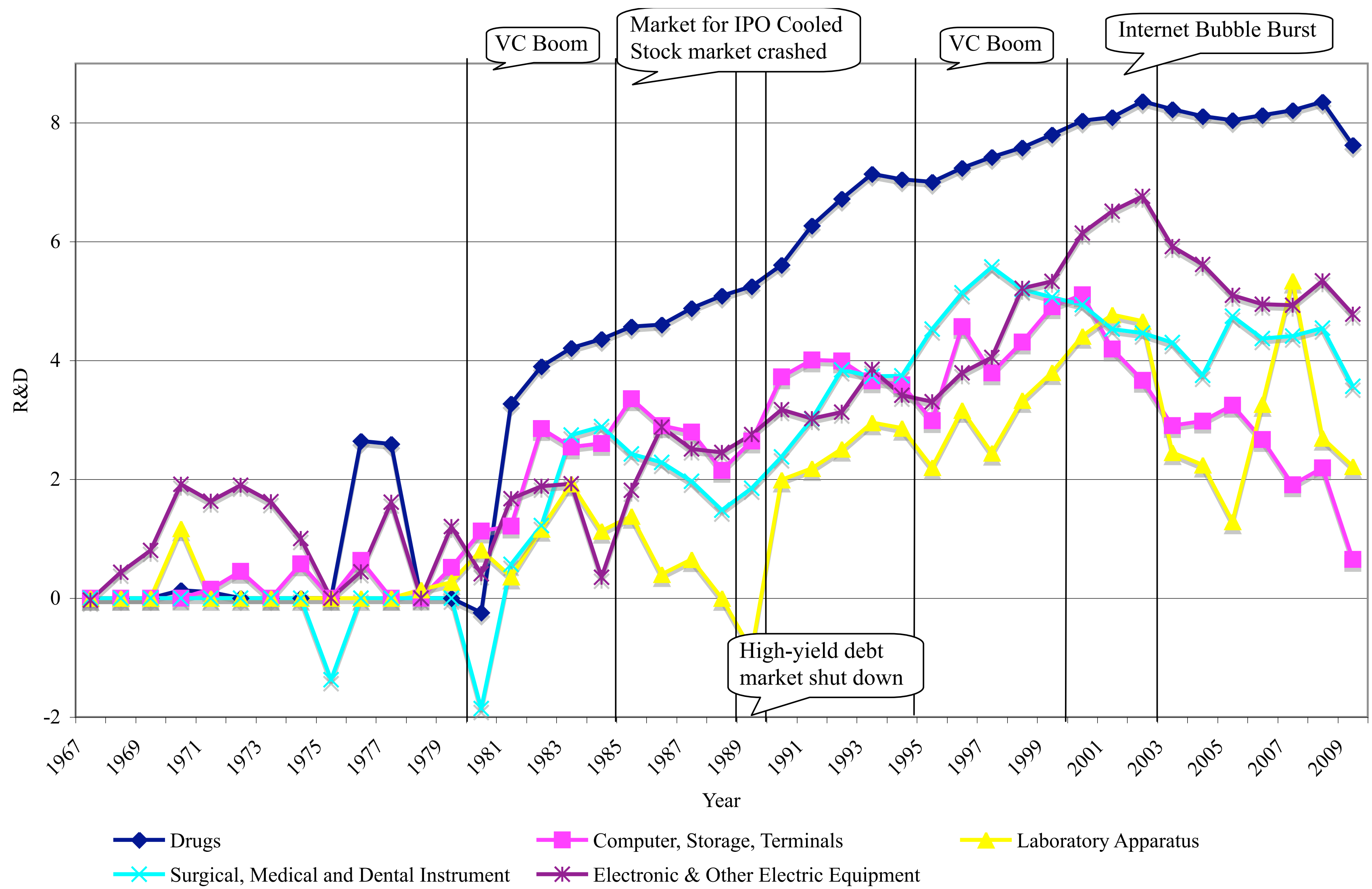

Table 1: Firm size distribution

	1976	1986	1996	2006
Mean	736.440	729.163	902.973	1,677.424
Median	71.223	39.525	47.217	60.912
Std Deviation	3,533	3,618	4,531	8,271
IQR	265.144	216.414	258.468	486.814
Obs	2,889	3,014	3,849	2,961

Table 2: OLS Regression of All Firms

	1976	1986	1996	2006
Log(Sales)	0.819	0.425	0.290	0.275
Constant	-4.456	0.351	-2.151	-1.612
R-square	0.695	0.467	0.317	0.306
obs	1,644	1,904	2,608	2,268
Industry Dummy	yes	yes	yes	yes

Table 3: OLS Regression of Large Firms Only

	1976	1986	1996	2006
Log(Sales)	0.953	0.860	0.839	0.857
Constant	-4.218	-4.068	-3.769	-4.925
R-square	0.777	0.774	0.732	0.730
obs	1,636	1,788	2,262	1,849
Industry Dummy	yes	yes	yes	yes

Table 4: Firm Type Distribution by Year

Percentage of R&D Expenditure by Firmtype 1950-2009

Year	Firmtype 1 (Revenue>R&D>0)		Firmtype 2 (R&D>Revenue>0)		Firmtype 3 (R&D>Revenue 0 or less)	
	----(Count)----	-----(Percent)----	---(Count)---	----(Percent)---	---(Count)---	---(Percent)---
1950	31	100.00 %		0.00 %		0.00 %
1951	41	100.00		0.00		0.00
1952	45	100.00		0.00		0.00
1953	49	100.00		0.00		0.00
1954	59	100.00		0.00		0.00
1955	69	100.00		0.00		0.00
1956	74	100.00		0.00		0.00
1957	79	100.00		0.00		0.00
1958	84	100.00		0.00		0.00
1959	87	100.00		0.00		0.00
1960	113	100.00		0.00		0.00
1961	120	100.00		0.00		0.00
1962	142	100.00		0.00		0.00
1963	148	100.00		0.00		0.00
1964	159	100.00		0.00		0.00
1965	176	100.00		0.00		0.00
1966	193	100.00		0.00		0.00
1967	202	99.51	1	0.49		0.00
1968	239	99.17	1	0.41	1	0.41
1969	242	98.78	1	0.41	2	0.82
1970	619	98.72	5	0.80	3	0.48
1971	1064	99.53	4	0.37	1	0.09
1972	1266	99.69	2	0.16	2	0.16
1973	1356	99.93	1	0.07		0.00
1974	1688	99.65	4	0.24	2	0.12
1975	1672	99.52	4	0.24	4	0.24
1976	1636	99.51	5	0.30	3	0.18
1977	1570	99.49	5	0.32	3	0.19
1978	1500	99.54	5	0.33	2	0.13
1979	1475	99.53	6	0.40	1	0.07
1980	1462	98.38	21	1.41	3	0.20
1981	1467	97.87	31	2.07	1	0.07
1982	1572	96.86	47	2.90	4	0.25
1983	1664	96.30	62	3.59	2	0.12
1984	1689	96.24	59	3.36	7	0.40
1985	1744	94.02	71	3.83	40	2.16
1986	1788	93.86	80	4.20	37	1.94
1987	1781	93.49	86	4.51	38	1.99
1988	1735	93.89	79	4.27	34	1.84
1989	1730	93.92	74	4.02	38	2.06
1990	1719	92.42	100	5.38	41	2.20
1991	1787	91.13	131	6.68	43	2.19
1992	1881	89.91	165	7.89	46	2.20
1993	1966	89.69	175	7.98	51	2.33

Percentage of R&D Expenditure by Firmtype
1950-2009

Year	Firmtype 1 (Revenue>R&D>0)		Firmtype 2 (R&D>Revenue>0)		Firmtype 3 (R&D>Revenue 0 or less)	
	----(Count)----	-----(Percent)----	---(Count)---	----(Percent)---	---(Count)---	---(Percent)---
1994	2028	88.44	190	8.29	75	3.27
1995	2218	86.88	237	9.28	98	3.84
1996	2262	86.73	266	10.20	80	3.07
1997	2217	86.77	271	10.61	67	2.62
1998	2240	84.82	318	12.04	83	3.14
1999	2174	84.13	317	12.27	93	3.60
2000	2101	84.68	295	11.89	85	3.43
2001	2003	83.60	297	12.40	96	4.01
2002	1948	83.14	286	12.21	109	4.65
2003	1946	83.16	279	11.92	115	4.91
2004	1949	82.38	304	12.85	113	4.78
2005	1899	81.40	311	13.33	123	5.27
2006	1849	81.53	310	13.67	109	4.81
2007	1805	82.01	288	13.08	108	4.91
2008	1719	82.60	257	12.35	105	5.05
2009	1626	85.53	184	9.68	91	4.79

Table 5: Composition of Size Variable

Variables	No. of Obs	% of Available Data
Employees	126,450	90.0%
Total Asset	138,692	98.7%
Market Value	109,251	77.8%
Book Value	133,742	95.1%
Property, Plant & Equipment	137,852	98.6%
Patent	106,211	75.6%

Table 6: Regression with other size variables including all firms

Year	Total Asset	Employee	Book Value	Capital
1976	0.94	0.95	0.91	0.81
	(0.013)	(0.014)	(0.014)	(0.013)
1986	0.85	0.85	0.84	0.68
	(0.011)	(0.013)	(0.012)	(0.011)
1996	0.81	0.79	0.85	0.61
	(0.011)	(0.013)	(0.012)	(0.011)
2006	0.76	0.76	0.84	0.55
	(0.011)	(0.014)	(0.013)	(0.011)

Table 7: Regression with other size variables excluding small firms

Year	Total Asset	Employee	Book Value	Capital
1976	0.95	0.97	0.91	0.82
	(0.013)	(0.014)	(0.014)	(0.013)
1986	0.90	0.92	0.87	0.77
	(0.011)	(0.013)	(0.012)	(0.011)
1996	0.89	0.89	0.91	0.72
	(0.011)	(0.013)	(0.012)	(0.011)
2006	0.89	0.89	0.92	0.72
	(0.011)	(0.016)	(0.013)	(0.012)

Table 8: Firm Type Distribution by Industry

Percentage of R&D Expenditure by Firmtype
By Industry
1980-2009

SIC	Firmtype 1 (Revenue>R&D>0)		Firmtype 2 (R&D>Revenue>0)		Firmtype 3 (R&D>Revenue 0 or less)	
	-----(Count)-----	----(Percent)----	----(Count)----	----(Percent)---	----(Count)----	----(Percent)---
200	211	99.53 %	1	0.47 %		0.00 %
201	99	100.00		0.00		0.00
202	132	98.51	1	0.75	1	0.75
203	200	99.50	1	0.50		0.00
204	229	99.13	2	0.87		0.00
205	55	93.22	1	1.69	3	5.08
206	104	100.00		0.00		0.00
207	48	85.71	3	5.36	5	8.93
208	157	89.71	12	6.86	6	3.43
209	121	90.30	5	3.73	8	5.97
210	24	100.00		0.00		0.00
211	122	98.39	1	0.81	1	0.81
220	122	99.19		0.00	1	0.81
221	57	100.00		0.00		0.00
222	61	100.00		0.00		0.00
225	104	100.00		0.00		0.00
227	40	100.00		0.00		0.00
230	28	100.00		0.00		0.00
232	24	100.00		0.00		0.00
233	43	100.00		0.00		0.00
234	26	100.00		0.00		0.00
239	28	100.00		0.00		0.00
240	85	100.00		0.00		0.00
242	5	100.00		0.00		0.00
243	54	93.10	4	6.90		0.00
245	50	100.00		0.00		0.00
251	198	100.00		0.00		0.00
252	172	100.00		0.00		0.00
253	90	100.00		0.00		0.00
254	82	100.00		0.00		0.00
259	32	100.00		0.00		0.00
260	47	100.00		0.00		0.00
261	70	92.11	1	1.32	5	6.58
262	267	100.00		0.00		0.00
263	92	97.87	2	2.13		0.00
265	90	89.11	2	1.98	9	8.91
267	441	99.77		0.00	1	0.23
271	13	86.67	2	13.33		0.00
272	25	100.00		0.00		0.00
273	60	98.36	1	1.64		0.00
274	38	77.55	4	8.16	7	14.29
275	114	96.61	4	3.39		0.00
276	57	100.00		0.00		0.00
278	25	100.00		0.00		0.00
279	2	100.00		0.00		0.00
280	240	99.17	2	0.83		0.00
281	520	96.83	7	1.30	10	1.86
282	493	90.79	45	8.29	5	0.92
283	4,990	51.91	3533	36.76	1,089	11.33
284	874	97.00	20	2.22	7	0.78
285	255	100.00		0.00		0.00
286	395	92.29	22	5.14	11	2.57

Percentage of R&D Expenditure by Firmtype
By Industry
1980-2009

SIC	Firmtype 1 (Revenue>R&D>0)		Firmtype 2 (R&D>Revenue>0)		Firmtype 3 (R&D>Revenue 0 or less)	
	-----(Count)-----	----(Percent)----	----(Count)----	----(Percent)---	----(Count)----	----(Percent)---
287	232	81.40	42	14.74	11	3.86
289	527	96.17	18	3.28	3	0.55
291	542	98.19	6	1.09	4	0.72
295	46	100.00		0.00		0.00
299	88	83.02	10	9.43	8	7.55
301	130	100.00		0.00		0.00
302	61	100.00		0.00		0.00
305	62	100.00		0.00		0.00
306	116	97.48	2	1.68	1	0.84
308	1,034	96.28	22	2.05	18	1.68
310	42	100.00		0.00		0.00
314	114	100.00		0.00		0.00
321	9	100.00		0.00		0.00
322	81	98.78	1	1.22		0.00
323	44	97.78	1	2.22		0.00
324	8	100.00		0.00		0.00
325	38	100.00		0.00		0.00
326	47	100.00		0.00		0.00
327	162	100.00		0.00		0.00
329	230	94.65	8	3.29	5	2.06
331	440	100.00		0.00		0.00
332	56	100.00		0.00		0.00
333	183	100.00		0.00		0.00
334	24	82.76	5	17.24		0.00
335	439	98.43	6	1.35	1	0.22
336	38	97.44	1	2.56		0.00
339	55	91.67		0.00	5	8.33
341	88	100.00		0.00		0.00
342	312	100.00		0.00		0.00
343	115	90.55	8	6.30	4	3.15
344	436	99.77	1	0.23		0.00
345	130	100.00		0.00		0.00
346	76	100.00		0.00		0.00
347	57	100.00		0.00		0.00
348	141	100.00		0.00		0.00
349	424	98.60	4	0.93	2	0.47
351	217	81.27	22	8.24	28	10.49
352	320	99.07	3	0.93		0.00
353	828	98.45	2	0.24	11	1.31
354	379	99.74	1	0.26		0.00
355	1,547	97.11	28	1.76	18	1.13
356	1,210	97.50	7	0.56	24	1.93
357	5,016	93.83	260	4.86	70	1.31
358	658	94.54	15	2.16	23	3.30
359	201	95.71	7	3.33	2	0.95
36-	12,456	94.57	571	4.34	144	1.09
371	1,611	98.17	22	1.34	8	0.49
372	692	97.88	4	0.57	11	1.56
373	130	100.00		0.00		0.00
374	85	100.00		0.00		0.00
375	65	92.86	1	1.43	4	5.71
376	150	96.77	5	3.23		0.00

Percentage of R&D Expenditure by Firmtype
By Industry
1980-2009

SIC	Firmtype 1 (Revenue>R&D>0)		Firmtype 2 (R&D>Revenue>0)		Firmtype 3 (R&D>Revenue 0 or less)	
	-----(Count)-----	----(Percent)----	----(Count)----	----(Percent)---	----(Count)----	----(Percent)---
379	136	97.14	1	0.71	3	2.14
381	748	98.03	12	1.57	3	0.39
382	4,114	94.60	192	4.41	43	0.99
384	4,865	84.71	586	10.20	292	5.08
385	198	93.84	10	4.74	3	1.42
386	555	98.23	9	1.59	1	0.18
387	13	92.86	1	7.14		0.00
391	3	100.00		0.00		0.00
393	16	100.00		0.00		0.00
394	620	99.04	2	0.32	4	0.64
395	75	100.00		0.00		0.00
396	36	100.00		0.00		0.00
399	328	91.36	19	5.29	12	3.34
999	159	100.00		0.00		0.00

Table 9: OLS Regression by Select Industry

	Drug	Computer	Elect. Equip	Lab Apparatus	Medical Equip
ln(Asset)	0.588	0.777	0.707	0.697	0.655
$\ln(VC_i)$	0.264	(-0.017)	0.095	0.161	0.153
R-square	0.701	0.827	0.745	0.768	0.668

Table 10: OLS Regression with Fixed Effects by Select Industry

	Drug	Computer	Elect. Equip	Lab Apparatus	Medical Equip
ln(Asset)	0.551	0.760	0.684	0.664	0.641
$\ln(VC_i)$	0.286	(-0.011)	0.091	0.166	0.147
R-square	0.699	0.827	0.745	0.768	0.668

Table 11: IV Regression with Fixed Effects by Select Industry

	Drug	Computer	Elect. Equip	Lab Apparatus	Medical Equip
VC_k	Computer	Drug	Drug	Drug	Computer
ln(S)	0.541	0.724	0.662	0.632	0.641
	(0.008)	(0.009)	(0.007)	(0.012)	(0.011)
$\ln(VCI_j)$	0.276	0.322	0.088	0.243	0.198
	(0.028)	(0.034)	(0.009)	(0.029)	(0.025)
R-square	0.698	0.833	0.748	0.774	0.670

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