THE EFFECT OF AMERICAN INDUSTRY DEREGULATION

ON

FIRM INNOVATION BEHAVIORS:

A DIFFERENCE IN DIFFERENCES APPROACH

by

Cong Gao

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics

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ABSTRACT

I exploit American economic deregulation in the entertainment, petroleum and natural gas, utilities, telecommunications and transportation industries to examine how the innovation activities of firms in these five industries changed following deregulation. By using a difference-in-differences method and using number of patents filed by firms through 1967-2004 as a proxy for innovation behavior, I find evidence that, in aggregate, following deregulation, the number of patents filed by firms in the five deregulated industries examined decline from 13.3% to17.3% in the subsequent one to five years after deregulation. Deregulation solely led to a 19.4% decline in innovation behavior, while the net increasing competition decreased innovation by 4.5%. Therefore, the results of this paper enrich current economic and corporate finance literatures by providing evidence of the effects of economic deregulation and show that economic deregulation has a negative effect on innovation activities of firms in the five deregulated industries. A further industry-by-industry analysis finds that, following deregulation, the innovation activity pattern of the petroleum and natural gas industries is different from the activity pattern of other four industries. This result sheds light on the real effects of economic deregulation 40 years after the deregulation process began.

Chapter 1

INTRODUCTION

In 1776, Adam Smith published "The Wealth of Nations" about the free-market system and presented the thesis that despite the apparent randomness and chaos of the free-market system, an "invisible hand" guides market forces as the result of individual self-interest. The philosophy is that when a man is pursuing his own needs, he benefits society more than if his intention was to help others rather than himself. This is part of the roots of the current concept of deregulation which refers to limiting government control over market forces and is espoused by those in favor of a free market. However, does economic deregulation really drive all aspects of the economy? How does economic deregulation influence innovation? This paper investigates the relationship between economic deregulation and the innovation behaviors in deregulated industries through empirical analysis using U.S firm level data.

For decades, regulation came under fire in the area of determining prices and business practices. Challenges arise from those who are in favor of free market: Why not depend on the discipline of the marketplace, with numerous sellers and service providers competing against each other, to determine prices? As this attitude became more prevalent in the 1970s-1980s, price and service regulation were removed in several industries. While maintaining some governmental oversight over safety and trying to prevent business abuses, price and entry regulation were lifted in the entertainment, transportation, petroleum and natural gas airlines, telecommunication and utilities industries. Commonly, people believe that, in the new deregulated economic environment, firms fight harder to innovate their way out of increasing competition and maintain their market share, while customers watch as the competitive industries introduce new services, products and lower prices to gain market share. Thus, understanding the real deregulation effect on a firm's innovation behavior is important.

For decades, economists have done theoretical and empirical research to investigate how regulation/ deregulation influence the economy growth. Innovation became one of the channels through which deregulation could promote the growth of the economy (Solow, 1957). Prior literature generates ambiguous predictions for the impact of economic deregulation on innovation behaviors. On the one hand, one group of economists believe that economic deregulation on price, quantity, enter and exist provides greater operating freedom and a more competitive environment and should stimulate new innovations. The public policy intervention such as deregulation might shape the forces for firm innovation activities by shocking the operating environment of firms. On the other hand, following Schumpeter (1942), another group of economists argue that innovation is best promoted in highly concentrated industries because increased competition reduces the monopoly rents that reward successful innovators.

However, the actual story isn't always as simple as people thought or as good as people expected. Despite significant research in this area, the understanding of innovation behavior is far from complete. Neither theory alone is capable enough to explain all regularities in innovation behaviors. Just like economic deregulation does not happen overnight, it takes even more time for deregulated industries and firms to adjust to the new competitive environment (Winston, 1998). Nowadays, about 40 years after the deregulation process began, it is worth finding out the truth of the story and investigating whether the regulation reform really boosted the firm innovation activity or not. This paper attempts to address this question and further our understanding of innovation behavior by studying changes of innovation behavior in response to economic deregulation.

I focus on the economic deregulations in five U.S. industries- entertainment, transportation, petroleum and natural gas airlines, telecommunications and utilities- that initiated from 1972-1999. I am studying the effect of deregulations on the innovation behaviors of firms in these five industries.

There are two main reasons why I focus on deregulation on these five industries. First, economic deregulations developed mainly for political and technical reasons and this is particularly the case for network industries such as entertainment, transportation, petroleum and natural gas, airlines, telecommunications and utilities, who are considered natural monopolies or relatively competitive traditionally. Over the last 40 years different industries have been deregulated in U.S. in the form of political policies. These industries were considered natural monopolies, but have now changed due to deregulation and introduction of new technologies. For example, in the utility industries, competition is in intense with the increased independent power producers and scale economies became less important with the introduction of combined cycle turbine. In the telecommunication industry, cellular phones now compete with land lines and internet calls; traditional text messages now compete with internet messages. Second, many network industries are oligopolistic or monopolies in natural, and deregulation is a much more complicated task for network industries than for non-network industries. During the period from the 1970s to the 1990s, other industries that are not considered natural monopolies were also deregulated as network industries, such as banking industries, the distribution of pharmaceuticals and the health sector. However, except for the banking sector, there was no real economic need for regulations, which implies that deregulation would be a much easier task than for networks (Jansson, 2008).

Table 1.1 Major deregulatory initiatives affecting entertainment, petroleum and natural gas, utilities, telecommunications and transportation industries, 1967-2004. Source: Viscusi, Harrington and Vernon (2005).

Year	Initiative
Entertainment	
1980	Deregulation of cable television(FCC)
1981	Deregulation of radio(FCC)
1984	Cable Television Deregulation Act
Petroleum and natural gas	
1978	Natural Gas Policy Act
1981	Decontrol of crude oil and refined petroleum products (executive order)
1989	Natural Gas Wellhead Decontrol Act of 1989
1992	FERC Order 636
Utilities	
1988	Proposed rules on natural gas and electricity(FERC)
1992	Energy Policy Act
1996	FERC Order 888
1999	FERC Oder 2000
Telecommunications	
1972	Domestic satellite open skies policy(FCC)
1979	Deregulation of satellite earth stations(FCC)
1980	Deregulation of cable television(FCC)
1980	Deregulation of customer premises equipment and enhanced services(FCC)
1981	Deregulation of radio(FCC)
1982	AT&T settlement
1984	Cable Television Deregulation Act
1988	Proposed rules on price caps(FCC)
1996	Telecommunications Act
Transportation	
1976	Railroad Revitalization and Reform Act
1977	Air Cargo Deregulation Act
1978	Airline Deregulation Act
1980	Motor Carrier Reform Act
1980	Household Goods Transportation Act
1980	Staggers Rail Act
1980	International Air Transportation Competition Act
1982	Bus Regulatory Reform Act
1984	Shipping Act
1986	Trading of airport landing rights
1987	Sale of Conrail
1993	Negotiated Rates Act
1994	Trucking Industry and Regulatory Reform Act
1995	ICC Termination Action
1998	Ocean Shipping Reform Act

Table 1.1 summarizes the details of all the major deregulatory initiatives. [1]And the regulatory reform in each industry is discussed and presented in detail as follows.

Entertainment industry was under price, content and entry regulation before 1979. By the late 1970s, the regulation paradigm underwent significant changes due to the growth of new technologies such as cable and subscription television. In 1984, the passing of the Cable Communications Policy Act of 1984 prohibited all regulation of basic cable service rates in areas where cable companies faced effective competition.

Petroleum and natural gas industry is different from the other four industries in that it is relatively competitive (Viscusi, Harringron and Vernon, 2005). Petroleum has a long and rich history of regulation. Its regulation focused on quantity at the very beginning by limiting the production of wells and oil importation in order to control price decline. In 1973 states stopped restricting domestic oil production and the regulation shifted to price. In 1981, concerned with the possible wealth transfer from consumers to oil producer, all remaining oil price controls were lifted by President Reagan. Deregulation of natural gas occurred in several steps, beginning with the Natural Gas Policy Act of 1978, which began limited decontrol of new gas prices. To encourage competition on a wider level still, the Federal Energy Regulatory Commission in 1986 and 1987 issued orders that required interstate pipelines to

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[1] Ovtchinnikov (2009) summarizes the major federal deregulatory initiatives affecting these industries according to Viscusi, Harrington and Vernon (2005). I extend Ovtchinnikov (2009)'s summary by adding two more deregulatory initiatives: The Domestic Satellite Open Skies Policy(FCC) for the telecommunication industry in 1972; the Ocean Shipping Reform Act for the transportation industry issued in 1998.

transport gas for any supplier. Essentially, the rules ensured "open access" to all providers and removed the pipeline companies as the sole wholesalers of gas (since they held a monopoly on transporting the gas). In 1989, gas prices were fully deregulated by Natural Gas Wellhead Decontrol Act of 1989.

The utilities industry was under price and entry regulation by the Federal Energy Regulatory Commission (FERC). Under the regulation, each utility had a service monopoly in a particular geographical region. The cost-of-service regulation ensured that the utility prices were stable and not subject to market volatility. The first significant change of the regulation was the passage of the Public Utilities Regulatory Policy Act of 1978, which gave qualifying facilities the right to sell power to vertically integrated utilities, and led to an increase in the number of non-utility power generators. In 1992, the passing of the Energy Policy Act gave rise to open-access transactions and formally introduced wholesale competitions.

Telecommunications experiences regulation in price and entry. Until 1984, American Telephone and Telegraph (AT&T) dominated the telecommunications business. Its 18 Bell Operating Companies provided local telephone service, while its Long-Lines Department handled almost all the nation's long-distance calls. In 1970, AT&T held $53 billion in assets and was the largest company in the world. It controlled a virtual monopoly in telecommunications because regulation prevented entry into the business by other companies and because it employed superior technology that few others could match. Deregulation of telecommunications took place as small, entrepreneurial companies, starting in the 1960s, sought to introduce new equipment for use on the AT&T network. Opposition by AT&T to these efforts led to a federal anti-trust suit and the company's divestiture in 1984 of the operating companies. Since divestiture, many companies have entered the long-distance business, and prices to customers have generally declined.

The transportation industry regulations focused on price and entry. Railroads' price regulation protected the railroads from increased competition from other transportation industries. In 1976, the Railroad Revitalization and Reform Act set up a "zone of reasonableness" within which railroads could adjust rates with the exception of those routes where railroads had "market dominance". Other deregulation acts passed during the 1980s and the 1990s gave the industry considerable freedom in setting rates as well as relaxed restrictions on entry and exist. The Airline Deregulation Act of 1978 began to dismantle the regulatory framework of the airline industry and ease itself out of existence. The regulatory protections of the federal government were lifted (except for safety, which remained under the regulatory watch of the Federal Aviation Administration), so that new airline companies could enter markets and so they could charge whatever fares they desired. However, by the mid 1990s, the top three airlines controlled almost 60% of the industry's revenue passenger miles. In some cases, individual airlines have virtual monopolies in city hubs such as Salt Lake City, Pittsburgh, Charlotte and St. Louis.

Overall, according to the nature of the five industries, their important deregulation initiatives that began in the early 1970s, and significant competitive environment changes, investigating the behavior of firms in these five industries will show us valuable evidence of the relationship of deregulation and firm innovation behavior. Visually, the time series of average number of patents applied by firms in the five deregulated industries shows a significant drop in absolute number through the period 1980-2004, which is indicated by the red and dashed line in Figure 1.1. However, the solid blue line in Figure 1.1 shows that 1980-2004 is a period that the firms in non- deregulated industries experience a technologies boom and their average number of patent applied kept increasing at the same period of time, 1980-2004. The opposite tendency of innovation activities of firms in two groups of industries leads me to investigate how the innovation behavior changes exactly following deregulation and why the innovation of firms in these five industries declined when innovation of other industries boomed in this dissertation.

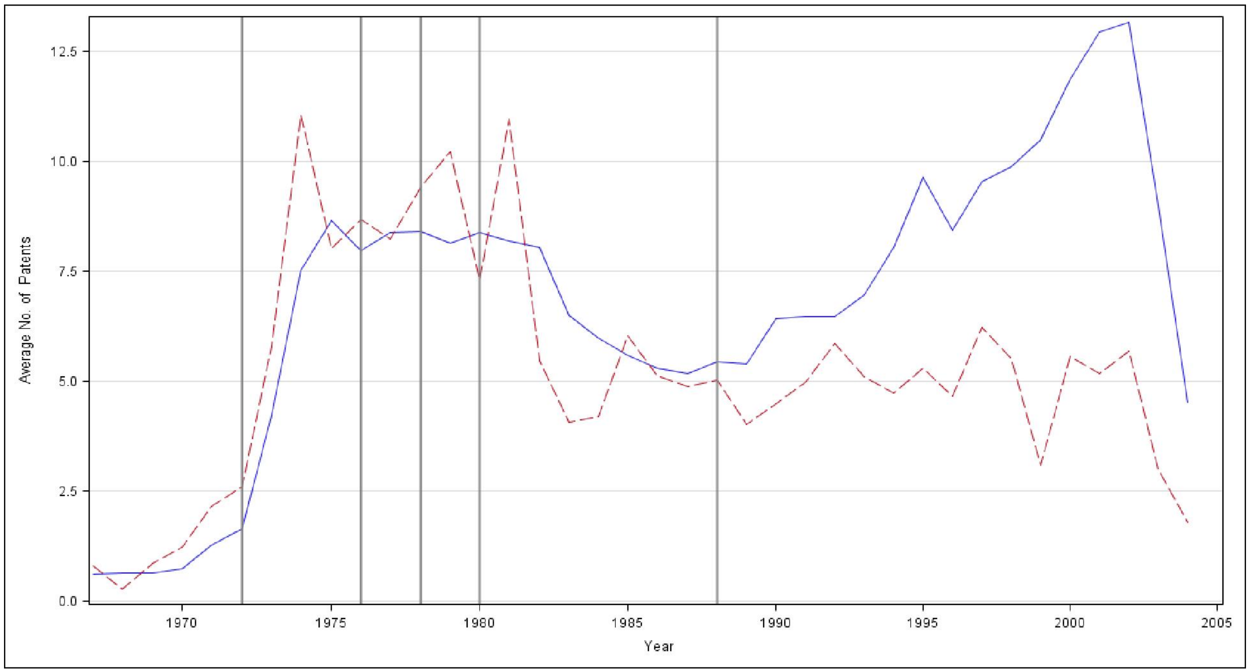

Figure **1.1 Average number of patents filed by firms in five deregulated industries and by firms in non-deregulated industries, 1967-2004.**

Red and dashed line indicates the trend of average number of patents filed by firms in five deregulated industries, while Blue and solid line indicates the trend of average number of patents filed by firms in non-deregulated industries, 1967-2004. The vertical thick line indicates the year of when the first significant deregulatory initiative is adopted for each of the five industries: 1980 for Entertainment, 1978 for Petroleum and natural gas, 1988 for Utilities, 1972 for Telecommunications and 1976 for Transportation.

Based on the results of previous studies, the oligopolistic nature of the five deregulated industries and the time series analysis of average number of patents applied for by firms in different industries, I hypothesize that economic deregulation in the five U.S network based industries has a negative effect on firm innovation activities.

I investigated the effects of two forms of economic deregulation in the U.S network-based industries: deregulation of price and quantity that allows firms to set prices and production quantities at competitive levels, and deregulation of entry that allows entry into an industry by new firms or by existing regulated firms and increases industry competition.

I employ the definition of "innovation" described by Grant (1997): innovation is the initial commercialization of invention by producing and marketing a good or service or by using a new method of production.

I employ the classification of industries of Famma-French 48 classification.

I begin my empirical analysis by constructing an unbalanced panel of firm-year data that includes patents information of these firms from the latest version of NBER PDP database, financial and accounting information of publicly listed firms from the COMPUSTAT database and dummy variables that indicate the economy deregulation initiatives years and deregulation group. As proxies for the level of innovation, I use the number of patents applied (finally granted) by firms each year through the sample period, 1967-2004. In order to make the analysis sufficient in finding out and examining the changing nature of firm innovation behavior, I also use the number of citations to these patents in each year on firm level as a measure of the quality of innovation (e.g., Bereskin and Hsu, 2013; Hall, Jaffe, and Trajetenberg, 2001). When constructing the dependent variable, I use one, two and three year lags in numbers of patents and citations and the cumulative number of patents and citations over the subsequent three or five years. The reason for the dependent variable setting is that I assume that the deregulation affects the innovation behavior with year lag and the granting of patent also has year lag.

In my main empirical model, I employ two-way fixed effects Ordinary Least Squares regressions, and use firms in non-deregulated industries to control for potentially confounding effects and thereby do difference-in-difference estimations: the difference in innovation behaviors of firms in deregulated industries before and after the deregulation compared to this difference for firms in non-deregulation industries during the same period. I find results consistent with my hypothesis. The economic deregulation reduced the number of patents filed by firms in deregulated industries by 12%. The results also indicate that the effect of deregulation becomes stronger as time passes.

To address potential concerns about reverse causality, I examine the dynamic effects of economic deregulation on the number of patents filed by firms during the whole sample period by introducing four timing dummies corresponding to four time periods around deregulations. I find that there is no effect prior to deregulation. Additionally, the time lag in the effects of economic deregulation is consistent with the fact that deregulation affects the innovation with long gestation periods. It takes time for firms to adjust to innovation strategies to reflect the new market conditions.

Next, I focus solely on firms in deregulated industries and propose a richer model that incorporates the interactions terms between the deregulation dummy and firm financial characteristics to illustrate the channels through which economic deregulation affected firm innovation. I find that after factoring in the direction and magnitude of the interactions terms, deregulation alone has led to a 19.4% decline in patenting in deregulated firms. The effect of a firm's profitability, which is an indicator of net competition effect, is significant following deregulation. For the sample period, the net competition effect is responsible for a 4.5% decrease in innovation.

My next set of tests focuses on each of the five deregulated industries separately to examine whether the effect of deregulation on firm innovation activities is uniform or industry specific. In the analysis in this part, I use matching firm procedures to draw inferences about deregulated firms. The matching firms work as the control groups of firms for each industry and are select from non-deregulated industries according to ROA, Tobin's Q and market value. The results are consistent with the previous analyses across most of the deregulated industries, except for the petroleum and natural gas industry.

Overall, the results of this dissertation indicate that economic deregulation has a significant impact on the firms' operating environments, which, in turn, significantly affects firms' innovation behaviors. Firms in the five deregulated industries respond to lower profitability and high competition resulting from deregulation by lowering innovation level, a behavior that is consistent with the prediction of the standard Schumpeterin model and prediction of Aghion et al. (2005).

The rest of the dissertation is organized as follows. Chapter two provides an overview of the relevant economic regulation and deregulation literature and innovation-related literature in the corporate finance field, the theory background and develops the hypotheses of the effects of deregulation on innovation behavior. Chapter three describes the data, sample and methodology used. Chapter four presents the empirical results of innovation behavior and its determinants in response to deregulation. Chapter five concludes.

Chapter 2

LITERATURE REVIEW

Espoused by those in favor of a free market, economic deregulation has become a trend since the early 1970s. Economists assert that public policy interventions such as deregulation may shape the forces for firm innovation activities by shocking the operating environments of firms. My study links the finance literature that examines the determinants of firm level innovation activities (e.g., Fang, Tian and Tice 2010, Hsu, Tian and Xu2013, Bereskin and Hsu2013,) and economics literature that exams real effects of economic regulation reform (e.g. Winston 1998, Sanyal, 2007, Nakada, 2005). On the one hand, although a large body of theoretical and empirical economics studies are discussing the impact of regulation reform on innovation, relatively little attention has been devoted directly to the impact of economic deregulation on firm level innovation behaviors in different industries. On the other hand, previous finance research has found innovation to be related to profitability, firm size, stock liquidity, CEO turnover related factors and et al.; however, how these will influence how factors act under an economic deregulation environment has been rarely discussed so far. My study contributes to the literature by focusing on an important micro-level channel, innovation, through which regulation reform impacts firm-level technological progress and further influences economic growth. I use a difference-in-difference method to examine the effects of deregulation. The current related researches are reviewed as follows.

2.1 Economic Theoretical and Empirical Research Related to Regulation Reform and Innovation

After decades of deregulation, Winston (1998) concludes that economic deregulation on price, quantity, enter and exist provides greater operating freedom and a more competitive environment and should stimulate new innovations. However, is it true that the competitive market is better than monopoly for innovation? This question has been under debate for decades by economists and numerous theoretical and empirical studies have been conducted to investigate how product market competition influences the firms' incentives to innovate. Theories of industrial organization suggest that the degree of competition plays a complex role in firms' innovative behavior, while empirical work also finds that the effect is mixed.

2.1.1 Theoretical studies: competition and innovation

Initially, it appears logical to think that firms in competition would have more incentive to innovate because of the need to outperform rivals with new and improved products or services.

However, competition may have an adverse impact on technological development. Schumpeter (1942) concludes new firms enter and may come to dominate an industry through creative destruction, because market power is endogenous to Schumpeterian growth.

Starting with Schumpeter (1942), as most models of endogenous growth (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992) describes, monopolistic rent from product markets is the main source of technological progress. Their models share the prediction that an increase in product market competition has a negative effect on productivity growth by reducing the monopoly rents that reward new innovation. Scherer (1967) have revealed that firms with higher market shares tend to have higher rates of R&D and innovate more.

Arrow (1962) questioned the Schumpeterian analysis of innovation. He pointed out that a pre-innovation monopolist has a weaker incentive to innovate than a firm operating in a competitive market. For a monopolist, innovation simply replaces one profitable investment with another, something that is called the "replacement effect" (Tirole, 1997). It can increase its profit by innovating, but it loses the profit that it enjoyed if no innovation takes place. On net the monopolist gains only the increment of its profits (Gilbert, 2006).The monopolist may actually receive a lower net return from introducing a new innovation that displaces the activities of the old one. Similarly, Williamson (1965) has shown that market competition positively affects the innovation activity. Van De Klundert and Smulders (1995) also mentioned that, if R&D is an in-house activity and the structure of the product market is imperfect, excessive concentration depresses innovation because large monopoly power induces firms to aim at higher prices rather than at innovation. Blundell, Griffith and Van Reenen (1995) developed a dynamic count data model and showed that when growing dominance increases industrial concentration, the level of aggregate innovation will tend to fall.

Based on the empirical evidence of the UK, Aghion, Bloom, Blundell, Griffith and Howitt (2005) argue for a non-monotonic relationship between product market completion and innovation. They also provide a theoretical rationale for this relationship. They classify the effect of product market competition into two kinds: the escaping competition and the Schumpeterian effect. The Schumpeterian effect has a negative effect on innovation, which is the case in sectors where incumbent firms are operating on different technological levels (with leaders and laggards).This is the case predicted by Schumpeter (1942): the competition mainly affects post-innovation rents, declining profits are expected following innovation, thus innovation is decreased. The escaping competition has a positive effect on innovation, which is pretty much the case of sectors where incumbent firms are operating at similar technological levels. In this case, innovation incentives depend on the difference between post-innovation and pre-innovation rents of incumbent firms. Competition will then increase the incremental profits from innovation. Pre-innovation rents are reduced. Innovating will be more profitable than doing nothing. Firms escape competition by innovating more. Thus, innovation is increased. According to (Aghion, Bloom, Blundell, Griffith and Howitt, 2005), when competition is low, and most of the competing incumbents are operating at a similar technological level, the escape competition effect is more likely to dominate. When competition is high, and a larger fraction of the sectors are laggard firms with low initial profits, the Schumpeterian effect will dominate.

Table 2.1 summarizes the predicted results of theoretical research on relationship between competition and innovation. The paper reviewed here found that the degree of competition plays a complex role in firms' innovative behavior. However, few of these paper provides convincing empirical support.

Table 2.1 Summary of theoretical research on relationship between competition and innovation and the results

Author (Year)	**Results of relationship**
Schumpeter (1942)	Negative
Romer(1990)	Negative
Grossman and Helpman(1991)	Negative
Aghion and Howitt(1992)	Negative
Scherer (1967)	Negative
Arrow (1962)	Positive
Williamson (1965)	Positive
Blundell Griffith and Van Reenen (1995)	Positive
Aghion, Bloom, Blundell, Griffith Howitt (2005)	invert-U

2.1.2 Empirical studies on the impact of regulation reform on innovation

When the theoretical research on the relationship of competition and innovation are well developed, a number of empirical studies about the effect of regulation and deregulation are conducted to confirm the theoretical prejudices of the era.

Economic literature distinguishes economic and social regulations.

Economic regulation sets market conditions and typically refers to government-imposed restrictions on firm decisions over price, quantity, and entry and exit. It is trying to avoid market failures generated by the behavior of single players within the market. The Stigler/Peltzman model suggests that the industries most likely to be regulated are those that are either relatively competitive or relatively monopolistic (Viscusi, Harringron and Vernon 2005). Casual observation suggests that it is indeed these two extremes that tend to be subject to economic regulation. Monopolistic industries include local and long-distance telephone service, electric and gas utilities, and railroads. Relatively competitive industries include agriculture, trucking, taxicabs, crude oil and natural gas production, and securities. During the periods of 1909-1970s, economic regulation was greatly expanded to encompass a large number of vital industries in the United States. However, since 1970s, partial or full deregulation of many of the regulated industries is entailed. This rising trend of economic deregulation continues to this day (Viscusi, Harringron and Vernon 2005).

Social regulation is the imposition of requirements on firms to protect the welfare of society or the environment and include health, safety and environmental regulation. Typically social regulation seeks to correct a market externality (Stewart, 2010). Since the early part of twentieth century, environmental and other social regulations have become an increasingly part of the regulatory mix. The recent emergence of concerns such as air pollution, global climate change and water quality has increased the stringency and extent of this form of regulation. As a result, unlike the economic regulation areas, there has been no major push toward social deregulation (Viscusi, Harringron and Vernon 2005).

The economic deregulation is the focus of this paper. Deregulation was supposed to allow new entry into the sector and facilitate competition. Empirical predictions of the effects of deregulation gave impetus to regulatory reform. Some economists assert that the wave of economic deregulation of U.S. industries in 1970s, 1980s and 1990s presents one of the most significant experiments in modern economic policy. As Blanchard and Giavazzi (2003) argued, understanding the effects of regulation reform in goods markets helps clarify the political economy constraints on deregulation and potentially improve its design. And as many countries are embarking on a path of deregulation, it may help interpret their macroeconomic evolutions. Baumol, Panzar, and Willig (1983) have circumvented debate about industry technology development and argued that even in industries with scale economies, deregulation may be superior to regulation.

The alleged benefits of economic deregulation in many industries prompted a debate on the growth effects from specific types of reforms of product-market regulation reform.

Winston (1993, 1998) concludes that various theories of regulation tended to predict that deregulation would enhance efficiency, and have a significant impact on deregulated industries by affecting market structure, competition, prices, employment, and consumer welfare. He argues that firms always made further adjustments responding to the regulation reform, and the innovation activity should be one of them.

Using counterfactual analysis, Winston (1998) examines how US industries, including airlines, motor carriers, railroads, banking and natural gas, adjusted to economic deregulation. He argues that adjusting to deregulation is time consuming, but society will continue to reap benefits from deregulation as industries continue to adjust to the new competitive order. The adjustment will raise consumer welfare significantly even at first, and increasingly over time. Under deregulation, firms seek out innovations in marketing, operations and technology and become more technologically advanced, so that they will become more efficient and more responsive to consumers. Deregulation has also led to improvements in corporate governance that contribute to innovative activity.

However, as of 1998, innovations in marketing, operations and technology are often difficult to anticipate, so the path of any particular industry as it adjusts to deregulation will be unpredictable (Winston, 1998). As of more recently, patent data set are much better built, which throws a wide open window to researchers to make empirical research on the economics of innovation (Jaffe and Trajtenberg, 2002).

Differently from most of the articles that discuss the deregulation effect, Sankov (2010) takes the deregulation timing into consideration. And he approaches the measurement of deregulation reforms in a fashion of using dummy variables. He finds that deregulation contributes to growth but its impact is different across countries, and the deregulation reform timing can at least partly explain the cross-country differences in the reform outcomes. Deregulating early and continuously is also associated with higher living standards.

More scholars have devoted considerable attention to the deregulation of specific industries and in particular to the effects of introducing competition. Jansson (2008) distinguishes industries into network industries and non-network industries. According to his classification, network industries almost natural monopolies like electricity, gas, telecommunication and transport. Non-network industries include the bank sector, pharmaceuticals and the health sector. And he indicates that, except for the banking sector, there was no real economic need for regulations for non-network industries. When reviewing this group of literature I can find that, on the one hand, most studies on economic regulation effects are narrowed in network industries and estimate the impact on innovations that "create benefits that firms can capture through the sale of goods and services in the market (Stewart, 1981)". On the other hand, a wide collection of literature focusing on the impact of social regulation covers both network and non-network industries.

Aghion, Alesina and Trebbi (2007) use industry-level data to demonstrate that within each economy, regulation reform influences different industries differently. Industries closer to the technology frontier will be affected more by deregulation and will innovate more than backward industries in order to prevent entry.

Harvey (1989) does a case study of the broadcasting industry of the UK and concludes that a deregulated broadcasting environment will have a beneficial effect on broadcasting generally, and serve as the guarantor of innovation and sensitivity to consumer preferences in particular.

Baltagi, Griffin and Rich (1995) analyze cost changes in the U.S. airline industry in the pre- and post-deregulation era using a panel data set of airlines. They find that the rate of pure technical change in the airline industry declined from 4.6 percent to 3.4 percent annually in the post-deregulation era: deregulation has had a pervasive effect on technical change and costs. The diminished growth rate of technical change can be linked directly to slower rates of adoption of more fuel efficient aircraft designs and slower relative improvements in load factor.

Prieger (2002) collects data on all CEI plan filings and waiver requests from 1987 through 1997 as his indicator for service innovation and finds that the decreased stringency in the economic regulation of telecommunications allows more market innovations.

Motivated to answer whether or not the U.S. government should join most of the rest of the world in regulating drug prices, Vernon (2003) employs a regression model to analyze data on the world's 20 largest pharmaceutical companies. He uses a one-period lead of percentage of firm pharmaceutical sales as the control variable of regulation. By simulating the effect of price control policy, he finds that economic regulation in the form of drug price controls would have a negative impact on the market innovation of new drugs. Moreover, the standard errors in his analyses are large, and thus the degree by which R&D intensity would decline is highly variable. When using a similar method, the same conclusion is found by adding the effect of drug importation regulation (Vernon, 2005) and by changing the regulation timing (Golec and Vernon, 2010).

Nakada (2005) modifies the growth model with vertical innovation (Aghion and Howitt, 1992) and concludes that, in the energy industry, when the elasticity of substitution between energy and labor is less than unity, deregulating the energy sector by increasing the number of energy suppliers encourages R&D activities for low-carbon energy technology, if initially the structure of energy market is highly concentrated. He also mentioned that the impact of deregulation depends on the number of energy suppliers in the economy. There is an inverted-U shaped relationship between product competition and R&D behavior. There is a critical level of deregulation below which deregulation encourages R&D activities for new energy technology.

Ongkittikul and Geerlings (2006) use twin characteristics approaches and case studies in the UK and Holland to examine the relationship between different regulation reforms and innovations in the transport sector. They argue that the innovations in service firms tend to be more driven by the market and by consumers. They conclude that in long run deregulation is likely to create more innovation than regulation.

Dietl, Grutter and Lutzenberger (2006) anticipate the upcoming deregulation of letter markets of the European Union and suggest that incumbents must decide on how much to invest in process and product innovations in order to be competitive once markets are deregulated. They analyze this decision process with a two-stage model with price competition and product differentiation. They distinguish between the regulatory scenarios of end-to-end competition and work sharing, and compare these scenarios with regards to the incumbents' innovation incentives. They find that the incumbents' incentives for process innovations in the upstream segment are stronger under end-to-end competition.

Sanyal (2007) finds that economic deregulation has had a substantial negative impact on public-interest environmental research conducted by electric utilities in the US from 1990 to 2001. However, the social regulation of 1990 Clear Air Act Amendments has adversely affected such expenditures.

Sanyal and Ghosh (2013) investigate how the deregulation of downstream industry influences the innovations of upstream industry. They focus on the electric equipment manufacturers and find that the downstream deregulation in the electric utility industry has a negative effect on the upstream innovation. They suggest that this result should have implications for all industries with a similar organizational structure as the electric utility industry.

Johnston (2010) uses patent data on a panel of 25 countries over the period 1978-2003 and finds that public policy plays a significant role in determining patent applications. Various policy instruments are effective for various renewable energy sources. He distinguishes six different policy types: R&D; investment incentives; tax incentives; tariff incentives; voluntary programs; obligations and tradable certificates. Binary dummy variables are constructed for different policy types to capture the effect of the implementation of different policies. Maximum likelihood method is used to estimate the parameters. They find that in general economic regulation has a positive effect on the innovation of all energy resources. They also suggest that instrument choice also matters. Taxes, obligations and tradable certificates are the only statistically significant policy instruments for renewable energy.

Blind (2011) uses the survey data based on the opinions of industry representatives as regulation indicators and patent applications of 21 OECD countries for the period between 1998 and 2004 to estimate the relationship between regulation and innovation through a weighted least squares regression with fixed effects. Because this is a cross-country analysis, no micro-level factor is considered in the paper. He finds that competition legislation is efficient in preventing unfair competition but has no significant positive influence on innovation. The price regulation is very positive for a country's innovative performance. These results prove Schumpeter's conclusion that monopolistic markets structures promote innovation is obviously in line with reality.

The relationship between deregulation and innovation has also motivated a voluminous empirical literature focusing on both developed and developing countries. Internationally, the 1990s witnessed the emergence of liberalization in many countries across the world through restructuring, competition, regulatory reform, and privatization. A group of studies is connected with liberalization and sheds a light on the relationship between liberalization and innovation activities.

Bowonder and Satish (2003) examine the innovation trends in the post-liberalisation period in India and indicate that there has been an increase in innovation-related activity in India. They argue that since the liberalization reform carried out starting in 1991, the Indian economy which was an inward-looking system under government control has changed in many ways. For a start, the national system of innovation has been affected by exposure to market forces and competition. Global firms have founded R&D centers in India and large private firms have increased spending on R&D. They also state that patentable innovations have shown a sharp rise since the opening up of the economy. Pharmaceutical, software and automobiles are three industries which in intense competition between transnational and Indian firms and the R&D intensity for these three industries is on the rise. They conclude that the Indian share of world trade is very low, and so there is a need for further expansion of R&D initiatives.

Aggarwal (2000) analyses the effects of the deregulation policy introduced in India in the mid-1980s on the relationship between technology imports and in-house R&D efforts. Using a dummy variable to control the regulation-deregulation period, Aggarwal examines the interactions between policy regime, economic environment and the determinants of inter-industry variation in technology imports in Indian manufacturing. In doing so, he introduces R&D efforts as one of the main determinants. The empirical results reveal that deregulation promotes complementarity between technology imports and R&D efforts significantly. The results also suggest that after deregulation, the impact of product differentiation, demand conditions and technology-related factors environment induced firms to update their technology.

Limiting their analysis to the liberalization process and the telecommunications industry, Calderini and Garrone (2001) present an empirical model to investigate the relationship between market structure shuffled by liberalization and the composition of

R&D activities. Using an data set including innovation measures from the incumbent public telecommunications operators of 17 European countries, they find that market liberalization provides firms with short-term incentives, shifting the allocation of resources towards applied and developmental activities. Thus, an increasing incidence of applied activities in the firms' research portfolio is shown.

Jamasb and Pollitt (2008) examines the impact of electricity reform on R&D activities within an industrial organization framework using UK data. They note that liberalization of the electricity sector has had significant implications for the landscape of energy R&D in the UK. In short-term, R&D productivity and innovative out-put per unit of input, such as patenting, appears to have improved. This finding is both intuitive and in line with the general improvements in the operating efficiency of the sector following deregulation. However, a lasting decline in R&D expenditure can have a negative long-term effect on technological progress and innovation in the sector. Winston (1998) suggested that to make sure that policy makers and the public do not sell deregulation short, it is useful to examine how the long-run efficiency benefits of deregulation are achieved.

As Stewart (2010) highlights, the empirical evidence of the impact of regulation reform on innovation is mixed so far. The precise impact is highly variable and case-specific.

Table 2.3 summarizes the empirical research on relationship between regulation/deregulation and innovation. The table shows whether the paper discussed economic regulation or deregulation, which industries it focus on, which countries' data us used by the paper and what are the empirical results. Most papers only investigate the regulation/deregulation effect on one particular industry, some paper research the cross-country effect, but few provides cross-industry empirical support. The effect of deregulation are different among different industries, thus there is not sufficient empirical evidence to support how the economic deregulation influence the whole economy innovation activities.

2.2 Finance Empirical Studies Related to Determinant Factors of Innovation

There is a fast growing finance literature that examines what factors influence the innovative activities.

Vivian Fang, Xuan Tian, and Sheri Tice (2013) find a negative relationship between stock liquidity and firm innovation productivity. They use the natural logarithm of weight-factor adjusted patent counts and citation-lag adjusted citations per patent as the main innovation measure.

Manso(2011) theoretically argues that incentive compensation, long vesting periods for unexercised options, tolerance for failure in short run and rewards success for the long run encourage a CEO to pursue innovative activities. Baranchuk, Kieschnick, and Moussawi (2011) examine data on a sample of U.S. IPOs from 2000 to 2004 and find evidence that is consistent with the prediction of Manso's (2011) model.

Hsu, Tian and Xu (2012) use the Arellano-Bond GMM procedure and report the different impacts of equity and credit market development on a country's innovation growth, measured by patenting. They find equity market development positively impacts innovation, while credit market development negatively impact innovation.

Bereskin and Hsu (2013) find that CEO turnover has a positive effect on a firm's output, efficiency, and innovation. They use a firm's patent counts, patent citations, patents per R&D dollar, and citations per patent in the subsequent three to five years as the measurement of firm innovation activity.

Table 2.2 summarizes the aspects that influence firm innovation behaviors that have been discussed by corporate finance empirical researches. All the papers discussed the effects in a "business as usual" environment, but none of them take the operation environment change following deregulation into consideration. How a firm's innovation activity reacts to economic deregulation is rarely examined by corporate finance literatures.

My study extends the literation in four ways. First, it contributes to the literature on economic regulation reform and growth by identifying a specific channel of innovation, through which regulation inform grow and providing empirical evidence from micro-level activities but from not macro-level economic perceives. Second, it also contributes to finance and innovation literature by examining factors that influence the innovative activities under deregulation environment. Third, it approaches the measurement of various deregulation reforms in a similar fashion to Standkov (2010) who transform the traditionally used reform indices into dummy variables in a way allowing difference-in-difference estimation. Fourth, it focuses on the relationship of innovation and deregulation of five deregulated industries, and finds the differences among different industries.

Table 2.2 Summary of corporate finance research on relationship between different aspects and innovation

Author (Year)	Aspect	Results of Relationship
Vivian Fang, Xuan Tian, and Sheri Tice (2013)	Stock Liquidity	Negative
Manso(2011)	Incentive Compensation, Tolerance for Failure	Positive
Baranchuk, Kieschnick, and Moussawi (2011)	Incentive Compensation, Tolerance for Failure	Positive
Hsu, Tian and Xu (2012)	Equity Market Development	Positive
Bereskin and Hsu (2013)	CEO Turnover	Positive

Table 2.3 Summary of empirical research on relationship between regulation/deregulation and innovation

Author (Year)	Regulation/Deregulation type	Researched industry	Researched counry	Resulted relationship
Winston(1998)	Economic Deregulation	Transport,banking, natural gas	U.S	Positive
Sankov (2010)	Credit,labor,Business Deregulation	N/A	Cross countries	Positive
Aghion, Alesina and Trebbi (2007)	Economic Reform	N/A	Cross countries	positive to technology frontier
Harvey (1989)	Economic Deregulation	Broadcasting	UK	positive
Baltagi, Griffin and Rich (1995)	Economic Deregulation	Airline	U.S	Negative
Prieger (2002)	Economic Deregulation	Telecommunication	U.S	Positive
Vernon (2003,2005,2010)	Economic Regulation	Pharmaceutical	World's top 20 firms	Negative
Nakada (2005)	Economic Deregulation	Energy	U.S	Inverted-U shaped
Ongkittikul and Geerlings (2006)	Economic Deregulation	Transport	UK and Dutch	Positive
Dietl, Grutter and Lutzenberger (2006)	Competition	Letter	European Union	Positive
Sanyal (2007)	Economic Deregulation	Electricity	U.S	Positive
Sanyal and Ghosh (2013)	Economic Deregulation	Electric equipment manufacturers	U.S	Negative
Johnston (2010)	Economic Regulation	Manufacturing	Cross countries	Positive
Blind (2011)	Ecnomic Regulation	Manufacturing	Cross countries	Positive
Bowonder and Satish (2003)	Liberalisation	Pharmaceutical, software, automobiles	India	Positive
Aggarwal (2000)	Deregulation	Technology imports	India	Positive
Calderini and Garrone (2001)	Liberalisation	Telecommunication	European countries	Positive
Jamasb and Pollitt (2008)	Regulation Reform	Electricity	UK	Positive

2.3 Testable Hypothesis

Hypothesis 0: *Economic deregulation lead to an increase in the level of innovation by firms in deregulated industries.*

Hypothesis 1: *Economic deregulation lead to a decrease in the level of innovation by firms in deregulated industries.*

The literature expects deregulation to have a significant impact on market competition environment and in turn affect firm innovation behaviors. Theoretically, on the firm level, deregulation affects innovation through two channels. First, price deregulations alter industry profits, hence the incentives to innovate. Second, both price and entry deregulations change the terms of entry, and hence change innovation decisions regarding new entry. These two channels work on my five deregulated industries as follows.

First, before deregulation, all of my five deregulated industries are oligopolistic or monopolies. After the price deregulation, with the instruction of competition, the profitability of the incumbent firms in the particular industry would decline due to increased competition with new entrants, and the more competitive market price of the final products compared to the high regulated price. Thus the capital of the incumbent firms which were often used for innovation would be reduced. According to Schumpeter (1942), enhanced market competition negatively affects technological progress by reducing the monopoly rents that reward new innovation. The decline in profitability also makes incumbent firms change their technology buying behaviors which in turn adversely affect the innovation activities of the upstream manufacturing firms in the industry (Sanyal and Ghosh,2013). This is actually the Schumpeterian effect defined by Aghion et al. (2009).

Second, both price and entry deregulations change the terms of entry, and an increase in entry threat may encourage the incumbent firms innovate, which is escape competition effect by Aghion et al. (2005, 2009). In the reconstructed industry, the incumbent firm has to fight harder to maintain and increase his market share. If he innovates then he will have a chance to become the technological leader firm in the industry and to be immune to entry. In other words, a firm close to the frontier responds to increased entry threat by innovating more in order to escape the threat. However, the new entry threat may discourage the innovation activity of laggard firms in the industry. For a laggard firm, no matter whether he innovates or not, he will remain behind the frontier because the frontier firm will not stop innovating. Thus, he would not choose innovate to way him out of competition, because he is unable to prevent the entrant from destroying the value of his innovation (Aghion et al., 2005).

Finally, the final effect of deregulation on aggregate innovation behavior depends on which of the two channels dominates. As proposed by Aghion et al.(2005), which of the two channels dominates depends on the fraction of advanced firms a in the economy. Following Schumpeterian growth models, competition and threat of entry induces incumbents in sectors that are close to the technology frontier to innovate more in order to escape entry. It reduces incumbents’ incentives to innovate in sectors that are further behind the frontier, where there is little hope of surviving entry. Thus, if the firms in the industry are neck-to-neck competitors, the second channel which has a positive effect on innovation will dominate. If the firms in the industry are unleveled as technological leaders and laggards, the first channel which has a negative effect on innovation will dominate.

For the research target of this paper, the five industries that experienced significant economic deregulations were: Petroleum and Natural Gas (30), Entertainment (7), Utilities (31), Communication (32) and Transportation (40). After deregulation, when new firms enter the market, all industries became unleveled with technological leaders and laggards. According to the discussion above, when competition is high, the industry has a large fraction of laggards, which means a larger fraction of sectors in equilibrium have innovations being performed by laggard firms with low initial profits (Aghion et al., 2005).Thus, Schumpeterian effect dominates. The increased competition would decrease the innovation activity of the industry on aggregate. Thus, I expect that economic deregulation lead to a decrease in the level of innovation by firms in deregulated industries.

Chapter 3

DATA AND METHODOLOGY

In subsection 3.1 I describe the data sources and sample selection. In subsection 3.2 I describe the construction of dependent variables and control variables used in this paper. In subsection 3.3 I discuss the model specification. I start by describing the data sources used to construct the dependent variables and control variables.

According to the research objective of this paper, how economic deregulation affects firm level innovation activities, I translate the research interest into an econometric model through three primary categories of data: the filed characteristic information of patents granted to U.S firms, dummy variables indicating the initiatives of economic deregulation activities and data of financial characteristics and other characteristics of given firms.

3.1 Data Source and Sample Selection

3.1.1 Data source

The first category of data, annual patents and citations information for each firm, are collected from the latest version of the National Bureau of Economic Research (NBER) Patent Data Project (PDP) database. The PDP database comprises detailed information on 3,210,361 U.S. utility patents applied for between January 1901 and December 2006, which were granted between January 1976 and December 2006[2]. Among these patents, 63,266 have up to 13 assignees. Thus, there are 3,279,509 firm-year observations of patents information in total. Patents that are assigned to more than one party have multiple records. The database also includes information of all citations received by these patents and made by patents granted between 1976 and 2006. There are 23,650,892 citations in total. Annual information on patent assignee names, assignee identifier, the number of patents, the number of citations received by each patent, a patent's application year and a patent's granted year are also available in the dataset.

The second group of data, economic deregulation activities, is indicated and used 0-1dummy as proxy. The initiatives of all the significant economic deregulation activities are collected and summarized by Viscusi, Harrington and Vernon (2005). I translate the deregulation initiatives into 0-1 dummies and use them as the proxy of economic deregulation. The information of the deregulation is discussed in chapter 1 and the construction for the deregulation dummies are discussed in Section 3.3 for details.

The third category of data, the financial and accounting information of given firms, are collected from the COMPUSTAT Industrial Annual Files database

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[2] The earliest patent application year was as early as 1901. The particular patent is applied as early as 1901, but was granted after 1976.

maintained by Wharton Research Data Services (WRDS). The COMPUSTAT annual files database reports the financial and accounting information of 27,145 U.S listed firms and corporations and contains 345,854 firm-year observations during the year period 1950-2006.

3.1.2 Sample selection

Following the method of Bessen (2009), I match the NBER PDP patent data to the COMPUSTAT data using a bridge file provided by the NBER PDP database in which GVKEY is the common identifier. The sample includes U.S. listed corporations and firms during the period of 1967 to 2004. I restrict the year from 1967 to 2004, because1967 is the fifth year before the first deregulation initiative discussed in this paper and 2004 is the fifth year after the last deregulation initiative discussed in this paper.[3]

Only information of manufacturing firms is included in the sample. There are two reasons for only including manufacturing firms in the sample: first, the matching between the patent dataset and COMPUSTAT by Hall et al. (2001) is done only for manufacturing firms; second, non-manufacturing firms (e.g. financial firms) usually operate under different regulatory rules(Atanassov and Nanda, 2005).

[3] The first deregulation initiative discussed in this paper is the 1972 Domestic Satellite Open Skies Policy in the telecommunications industry. The last deregulation initiative discussed in this paper is the FERC Oder 2000 to Utilities industry, which was passed in 1999. Thus, 1967 is the fifth year before 1972 and 2004 is the fifth year after 1999.

I also require that all firm-years have non-missing data for book assets, profitability, market-to-book and fixed assets. To minimize the effect of outliers, all variables are winsorized at the top and bottom one-percentiles of each variable's distribution[4]. The final sample is an unbalanced panel of 101,355 firm-year observations during 1967-2004.

The industry definitions used in this paper follow Fama-French 48 industry classifications from Ken French's web site. In order to find out how the industry deregulation influences the firm level activities, it is important to decide first which firms belong to which industry. Traditionally, Standard Industrial Classification (SIC) codes, which aggregate firms selling related end-products or using similar production processes in an industry, has been used for this purpose(Chan,Lakonishok and Swaminathan,2007). However, changes in the variety of products, the growing importance of services together with shifts in technology and in the makeup of businesses, have called into question the usefulness of the SIC system (Clarke, 1989). More recently Fama and French (1997) start from firms' 4-digit SIC codes and reorganize them into 48 industry groupings. The Fama-French (FF) classification has been highly influential and has been widely used in many empirical studies in corporate finance (e.g. Hsu, Tian and Cu (2012), Ovtchinnikov (2008), Fang, Tian and Tice (2010), Hsu and Bereskin (2013)) and in economics (Hugon, Kumar and Lin

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[4] A similar method is used by Atanassov and Nanda (2005), Fang,Tian and Tice(2010) and (Ovtchinnikov, 2008) when research the firm level innovation activities.

(2013), Bebchuk and Grunstein (2005), Wulf (2002)). Worth noticing: Fama and French do not provide any evidence on how well their classification system produces groups of economically similar firms (Chan, Lakonishok and Swaminathan, 2007). Some researchers also argue that the Fama-French industry definitions are too broad. However, for the characteristics of the research topic of this paper, I agree with Otvtchinnikov (2008)'s argument that although industries are often deregulated only one specific segment at a time, deregulation actually impacts all firms in an industry. Taking this into account, the Fama-French classification is appropriate for the analysis.

3.2 Variable Construction

3.2.1 Dependent variable: Proxies for the quantity and quality of innovation

3.2.1.1 Define innovation

Before proceeding, it is important to define innovation. O'Sullivan and Dooley (2008) define innovation as the process of making changes, large and small, radical and incremental, to products, processes, and services that result in the introduction of something new for the organization that adds value to customers and contributes to the knowledge store of the organization. When defining innovation, it is appropriate to define the distinction between innovation and invention. Grant (1997) defines an innovation as distinct from an invention:" Invention is the creation of new products and processes through the development of new knowledge or the combination of existing knowledge... innovation is the initial commercialization of invention by producing and marketing a good or service or by using a new method of production." Palangkaraya, Stierwald,Webster and Jensen (2010) regard innovation as an outlay made by firms in the expectation of future benefits. Innovation differs from invention in that innovation refers to the use of a better and, as a result, novel idea or method, whereas invention refers more directly to the creation of the idea or method itself. An example of this would be the distinction between the invention of telephonic transmission and the innovation of the telephone system (Scherer, 2013). Consistent with Grant (1997) and others (Schumpeter, 1934) the definition of innovation used in this paper focuses on the development of commercially viable products or services from creative ideas.

3.2.1.2 Commonly used proxies for innovation

Traditionally, both R&D expenditure and patent counts data have been frequently used to measure innovation. However, the use of R&D expenditure as a proxy for innovation is foremost problematic. The main reason is that not all firms report their R&D expenditure. Strategically, whether or not to report R&D expenditure and what to report varies depending on how the firm wants to distribute their earnings and profits, how to benefit tax and how to inform the stock market, etc. As a result, there is high incidence of missing data for R&D expenditure in accounting-based firm data sets. For researchers, it is hard to tell whether the missing R&D data are missing for strategic reasons or are true zeros.

More recently, when the data on patents and patents' detailed information are available and well developed, counting the number of patents produced by a country, an industry, a firm, or an inventor becomes a popular method to measure for the innovation quantity and its quality. The long time series, firm-level dataset provides information on inventions that are both new to the firm and to the world, based on which a variety of original measures constructed with patent data and citation data have been developed, including patent counts, forward and backward citation, self-citation, originality, generality, number of patents per company, etc. It is argued that there are also some limitations to the use of patent data. One of the most glaring is the fact that not all inventions are patented. Only inventions that are novel, non-trivial and have commercial application meet the patentability criteria set by USPTO. However, this paper defines the innovation as the initial commercialization of invention, the patent counts become an appropriate index for innovation and the limitation is no longer a limitation for the particular case. In contrast to R&D expense, which represents the input to innovation, patents and citations capture the output of innovation and is widely accepted in capturing technological advances.

3.2.1.3 Proxies used in this paper

The proxies for the quantity and quality of innovation in this paper are constructed from the latest version of NBER PDP database. Based on the availability of the information in the NBER PDP database, I measure the level of firm-year innovation output using the following two proxies.

Firstly, the number of patents is used to measure the productivity and quantity of innovation output: this variable is a simple count of the number of distinct patents applied (and subsequently granted) by firm *i* in year *t*, $PCounts_{i,t}$. Secondly, the number of citations is used to measure the importance of a patent and the quality of the innovation output: this variable is defined as the number of backward citations to patents applied for (and subsequently granted) by firm *i* in year *t*, $CCounts_{i,t}$[5],a more important patent has a better quality.

It is worth noting that, following the existing innovation literature, the patent counts and citations are counted by their application years, but not granted years. The inventors have a strong incentive to apply for a patent as soon as possible following the completion of the innovation, whereas the grant date depends upon the review process at the Patent Office, which takes on average about 2 years (Volodin, 2010). Thus, the actual timing of the patented inventions is closer to the application date than to the grant date. "Whenever possible, the application date should be used as the relevant time placer for patents" (Hall, Jaffe and Trajtenberg, 2001). It is important to note that although the application year is used as the relevant year for the analysis, the patents appear in the NBER PDP database only after they are granted.

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5 Pakes and Griliches (1980) show that the distribution of the importance of patents is extremely skewed and that most of the values are concentrated in a small number of patents. Hall, Jaffe and Trajtenberg(2001,2005) analysis that patent citations are a good measure of the value of innovations. Similar methods are used by), Fang, Tian and Tice (2010), and Hsu and Bereskin (2013).

Table 3.1 Application-grant lag distribution by 5-year sub-periods of the whole sample

	Application years							
	1967-71	1972-76	1977-81	1982-86	1987-91	1992-96	1997-01	2002-06
Lag (years)	Distribution of lags (in %)							
0	0	0.59	0.55	0.85	2.27	1.53	0.58	1.39
1	0	30.85	25.3	26.81	40.97	29.61	19.67	24.02
2	0	52.04	51.89	48.7	42.45	44.24	40.29	43.21
3	0	11.18	17.59	17.57	10.58	16.54	21.73	22.94
4	0	3.08	2.76	3.58	2.45	4.31	9.77	8.45
5	31.01	1.28	0.94	1.38	0.66	1.61	5.45	0
6	21.26	0.44	0.49	0.64	0.25	0.97	1.81	0
7	13.26	0.19	0.23	0.23	0.13	0.62	0.52	0
8	8.43	0.11	0.09	0.08	0.09	0.31	0.14	0
9+	26.04	0.24	0.16	0.16	0.15	0.26	0.04	0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mean and standard deviation of the lag (years)								
Mean	8.11	1.96	2.05	2.06	1.76	2.08	2.48	2.13
S.d.	4.86	1.14	1.02	1.05	0.97	1.19	1.26	0.92

As suggested by Hall, Jaffe and Trajtenberg (2001), the truncation bias should be taken into consideration when using data from NBER PDP database. Following the existing innovation literatures, there are two kinds of truncation bias. The first truncation bias is regarding the patent counts, because patent data timed according to the application date will increasingly suffer from missing observations consisting of patents filed in recent years that have not yet been granted. Following the method used by Hall, Jaff and Trajtenberg (2001), using updated patent data, Table 3.1 shows the distribution of application-grant lags for 5 years' sub-periods from 1967 to 2004, as well as the mean lag and its standard deviation. The lag is significant and is not monotonic. Before 1970s, the lag is large and has an average of 8.11 years. The database includes all patents that were granted since 1976, and the beginning of the sample is 1967. Thus, patents applied for in 1967 in this sample were granted as late as 1976 and had an application lag of 9 years at least. However, the database doesn't observe the patents that were granted so quickly that their grant date is before 1976. This suggests that it is appropriate to correct the application counts for 1967-1976. However, during the first half of 1980s the lag is lengthened compared to the lag of 1970s, and shorten in the second half of 1980s; then it is lengthened for the whole 1990s, and shortened again since the 2000s. The average lag is in the range of 1.76 years to 2.48 years. Following Hall, Jaff and Trajtenberg (2001), I correct the simple patent counts using the "weight factors" computed from the application-grant empirical distribution. Then I multiply each simple patent count ($PCounts_{i,t}$) by the corresponding weight factor. Then I get the new dependent variable $PCounts^{a}_{i,t}$, which is the weight factor adjusted patent counts of firm *i* in year *t*. In contrast to $PCounts_{i,t}$ which is a count variable, $PCounts^{a}_{i,t}$ is a continuous variable. The details of the distributions of lag years and un-weighted / weighted number of patents in the Sample from 1976 to 2006 in each application year-grant year combination are showed in Appendix A, Table A.1.

The second kind of truncation bias is regarding the citation counts. As shown in Figure 3.1, a gradual decline in the number of citations received in recent years is observed. This is because a patent can be cited in subsequent years but only citations received up to 2006 can be observed. Following Hall, Jaff and Trajtenberg (2001), for older patents truncation is less of an issue and the truncation in citation counts can be corrected by estimating the shape of the citation-lag distribution. To correct the citation truncation problem, I scale the citation counts using the citation truncation weight from the NBER PDP dataset and I get a new dependent variable $CCounts^{a}_{i,t}$, which is the truncation adjusted citation counts of firm *i* in year *t.* The same as patent count data, after the truncation adjustment, in contrast to $CCounts_{i,t}$ which is a count variable, $CCounts^{a}_{i,t}$ is a continuous variable.

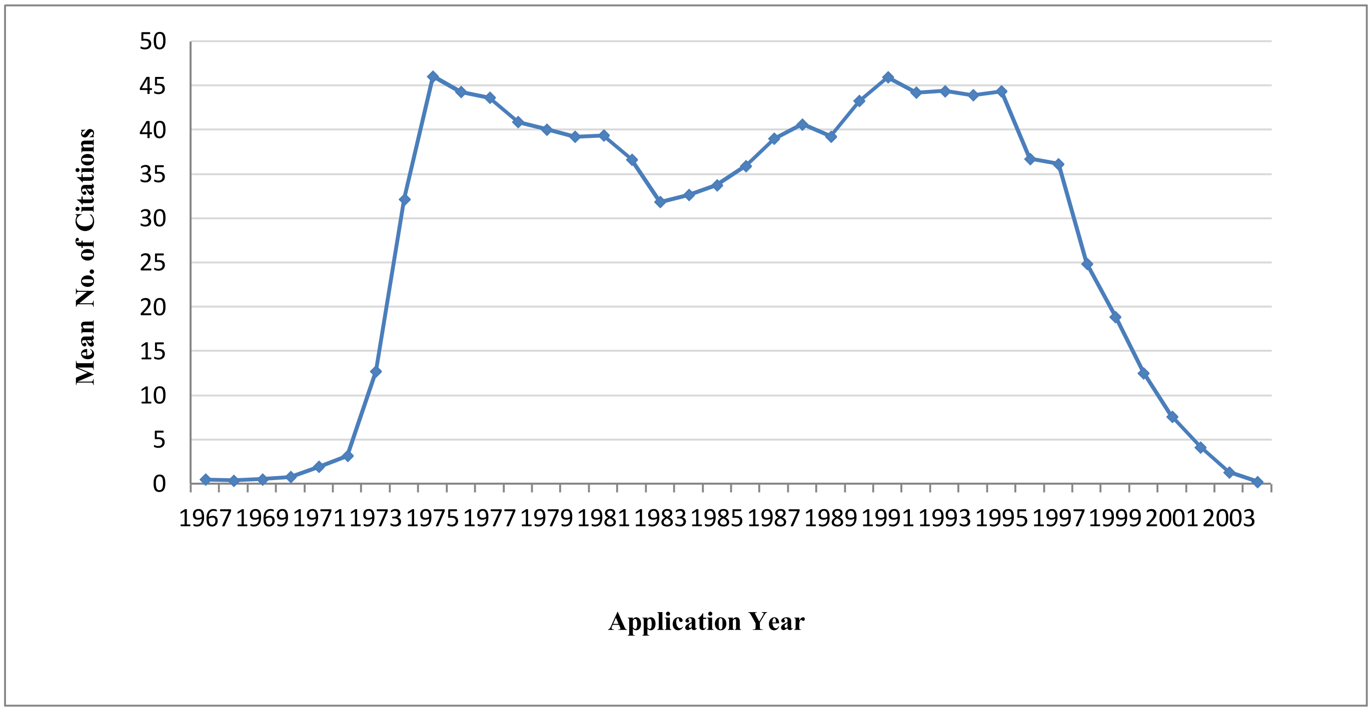

Figure 3.1 Average number of citations received in recent years, 1967-2004.

One characteristic of the patent counts and citation counts used in this paper is that their distribution is right skewed. The unconditional mean of our outcome variables is much lower than its variance which suggests that over-dispersion is present. Traditionally, negative binominal model is good for fixing this problem. However, adjusted patent counts and adjusted citation counts are continuous data but not count data. Thus, negative binominal model is not appropriate. To solve this problem, I use the natural logarithm of the total number of the weighted factor adjusted patent counts in year *t+1, t+2, t+3* ($LnPCounts^{a}_{i,t+n}$) and truncation adjusted citation counts in year *t+1,t+2, t+3* (Ln $CCounts^{a}_{i,t+n}$), respectively. It is worth paying attention to the issue that about 68.01% of firm-year observations of the sample used in this paper have zero patents[6]. The number of zero patents is significant. With the natural logarithm approach, data will be lost due to undefined values generated by taking the log of zero. Thus, following Fang,Tian and Tice (2010), I add one to the actual values to avoid losing observations with zero patents or zero citations when calculating the natural logarithm. The formula is as follows:

$LnPCounts^{a}_{i,t+n}$= Ln (1+ $PCounts^{a}_{i,t}$), n=1,2,3

$LnCCounts^{a}_{i,t+n}$ = Ln (1+ $CCounts^{a}_{i,t}$), n=1,2,3

Reflecting on the long term nature of investment in innovation, following Bereskin and Hsu (2013), I also construct the following cumulative forms of measure

[6] This is comparable to that reported in Fang,Tian and Tice (2010),i.e. 75%, and Atanassov, Nanda and Seru(2005),i.e. 84%.

as the proxies for innovation performance. Similar reason as above, one is added to the formula to avoid losing observations with zero patents:

$$PCounts^a 3yr_{it} = Ln\ (1 + PCounts^a_{i,t+1} + PCounts^a_{i,t+2} + PCounts^a_{i,t+3})$$

$$PCounts^a 5yr_{it} = Ln\ (1 + PCounts^a_{i,t+1} + PCounts^a_{i,t+2} + PCounts^a i_{,t+3} + PCounts^a_{i,t+4} + PCounts^a_{i,t+5})$$

$$CCounts^a 3yr_{it} = Ln\ (1 + CCounts^a_{i,t+1} + CCounts^a_{i,t+2} + CCounts^a_{i,t+3})$$

$$CCounts^a 5yr_{it=}\ Ln\ (1 + CCounts^a_{i,t+1} + CCounts^a_{i,t+2} + CCounts^a_{i,t+3} + CCounts^a_{i,t+4} + CCounts^a_{i,t+5})$$

which are the log of one plus patent counts or citations over the following five-year or three-year periods.

3.2.2 Independent variables：deregulation dummies

3.2.2.1 Define economic deregulation

Merriam-Webster's Collegiate Dictionary defines "deregulation" as the act or process of removing restrictions and regulations. According to economic literature, economic deregulation is defined as deregulation of entry, exit, price, and quantity. It is opposite of economic regulation. “Deregulation of entry allows entry into an industry by new firms or by existing regulated firms and increases industry competition. Deregulation of exit allows existing firms to exit unprofitable lines of business and shed excess capacity. Deregulation of price and quantity allows firms to set prices and production quantities at competitive levels” (Ovtchinnikov, 2008).

The major Federal deregulatory initiatives affecting entertainment, petroleum and natural gas, utilities, telecommunications and transportation industries during 1972-2003 are summarized from Viscusi, Harrington, and Vernon (2005)[7]. Table 1.1 summarizes the details of all the major deregulatory initiatives and the regulatory reforms in each industry are discussed and presented in greater detail in Chapter One.

3.2.2.2 Deregulation dummies used in this paper

To implement the empirical model and control for the effects of economic deregulatory events, I identify two deregulation dummies as follows: (a) $Deregind_{it}$ is the dummy that identifies the industry classification of firm i. The dummy switches to one if a firm operates in one of my five deregulated industries listed in Table 1.1, and keeps zero otherwise. (b) $Deregtime_i$ is the dummy indicates the adoption of deregulation initiatives. This dummy switches to one the years after the first significant deregulatory initiative affecting the industry is adopted for firm i, and keep zero otherwise.

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[7] Ovtchinnikov (2009) summarizes the major federal deregulatory initiatives affecting these industries according to Viscusi, Harrington and Vernon (2005). I extend Ovtchinnikov (2009)'s summary by adding two more deregulatory initiatives: The Domestic Satellite Open Skies Policy(FCC) to the telecommunications industry in 1972; the Ocean Shipping Reform Act to the transportation industry issued in 1998.

3.2.3 Independent variables: firm financial characteristics control variables

In this paper, I conduct the tests with firm level data and I consider a vector of firm characteristics that account for the nature of the firm and may affect a firm's future innovation output. Following the innovation literature, I compute the following financial variables for firm *i* over its fiscal year *t*: ROA (return on assets ratio) measures the profitability of the firm; leverage ratio (debt-to-asset ratio) measures the firm's ability to meet financial obligations; investment in intangible assets, which is valued by R&D expenditures-to-assets ratio, shows the potential innovation and competitive advantage of the firm; asset tangibility (PPE-to-assets ratio) affects the firms' investment economically significantly (Almeida and Campello, 2007); capital expenditure is calculated by dividing capital expenditure by total assets; Tobin's Q is calculated for the growth opportunity of the firm; The natural logarithm of book value assets is calculated to control corporation size. I include the Herfindahl Index based on sales and constructed on Famma-French 48 industry level to control for the industry concentration. Moreover, according to Aghion et al. (2005), there is an inverted-U relationship between competition and innovation. In order to mitigate this non-linear relationship, the squared Herfindahl Index is included in the model. The firm age is measured by the natural logarithm of one plus the number of years the firm is listed on COMPUSTAT. Variable definitions are described in detailed in Table 4.2**.**

Table 3.2 Variable Construction

Variable	Definition
Dependent Variable: Measures of innovation	
$PCounts_{i,t}$	Denotes the number of distinct patents granted by a firm *i* in year *t*, a count variable;
$CCounts_{i,t}$	Denotes the number of citations received by a firm *i* in year *t*, a count variable;
$PCounts^{a}_{i,t}$	Denotes the weight factor adjusted patent counts of firm *i* in year t, a continuous variable;
$CCounts^{a}_{i,t}$	Denotes the the truncation adjusted citation counts of firm i in year *t*, a continuous variable;
$LnPCounts^{a}_{i,t+n}$	Denotes the natural logarithm of one plus the total number of the weighted factor adjusted patent counts of firm I in year *t+1*, *t+2, t+3*,repectively;
$LnCCounts^{a}_{i,t+n}$	Denotes the natural logarithm of one plus the total number of truncation adjusted citation counts of firm *i* in year *t+1, t+2, t+3*,repectively;
$LnPCounts^{a}3yr_{it}$	Denotes the natural logarithm of one plus the cumulative total number of the weighted factor adjusted patent counts of firm *i* from year *t+1* to *t+3*;
$LnCCounts^{a}3yr_{it}$	Denotes the natural logarithm of one plus the cumulative total number of truncation adjusted citation counts of firm *i* from year *t+1* to *t+3*;
$LnPCounts^{a}5yr_{it}$	Denotes the natural logarithm of one plus the cumulative total number of the weighted factor adjusted patent counts of firm *i* from year *t+1* to *t+5*;
$LnCCounts^{a}5yr_{it}$	Denotes the natural logarithm of one plus the cumulative total number of truncation adjusted citation counts of firm *i* from year *t+1* to *t+5*;
Regressors: Dummy variables	
$Deregind_{it}$	Indicates whether the firm is in one of the five industries that

	under deregulation. It turns to one if the firm is in one of the five deregulated industries: entertainment:Fama-French 48 industry 7, petroleum and natural gas: industry 30, utilities: industry 31, telecommunications: industry 32, transportation: industry 40;
Deregtime$_{it}$	Turns to one the year after the first initiative of deregulation for each industry (for years 1981-2004 for entertainment, 1979-2004 for petroleum and natural gas, 1989-2004 for utilities, 1973-2004 for telecommunications, 1977-2004 for transportation);
Regressors: Firm level financial variables that measure firm characteristics	
HHI_{it}	Herfindahl-Hirschman Index of 4-digit SIC industry where firm I belongs. It is calculated by squaring the market share of each firm competing in a market, and then summing the resulting numbers. Market share is measured using sales at end of fiscal year *t*;
HHI^2_{it}	The square term of HHI_{it};
Ln_age$_{it}$	Natural logarithm of one plus firm I's age. Firm I's age is calculated by the number of years listed on Compustat;
Ln_mv$_{it}$	Natural logarithm of firm I's market value of equity (Shares outstanding x Stock price) at the end of fiscal year t;
$RDAT_{it}$	R&D-to-assets ratio calculated as research and development expenditure divided by book value of total assets measured at the end of fiscal year t, set to 0 if missing;
ROA_{it}	Return-on-assets ratio calculated as operating income before depreciation divided by book value of total assets at the end of fiscal year t;
$PPETA_{it}$	Fixed assets-to-assets ratio calculated as property plant and equipment divided by book value of total assets at the end of fiscal year t;
LEV_{it}	Firm's book leverage ratio calculated as book value of debt divided by book value of total assets;
$CAPEXTA_{it}$	Capital expenditure divided by book value of total assets at the end of fiscal year t;
Tobin's Q_{it}	Market-to-book ratio= (market value of equity+ book value of assets-book value of equity-deferred taxes)/book value of assets.

3.3 Model Specification

The main econometric model focused on the relationship between indicator variables of economic deregulation and the proxies for the quantity and quality of innovative activity.

The empirical specification model I estimate is as follows:

$$Y_{it} = \alpha + \beta_1 Deregind_{it} + \beta_2 Deregind_{it} \times Deregtime_{it} + \sum_{J=1}^{j} \theta_j X_{it}^{j} + \vartheta_t + \gamma_j + \varepsilon_{it}$$

Considering the identification of variation across time and industries, industry fixed effects and year fixed effects are included in the model. The industries indictor dummy is used to control all time-invariant characteristics of the industry that might influence its innovative output.

To conduct the empirical analysis, I use two-way fixed-effect OLS Regression.

The coefficient of the interaction of industry indicator dummy and deregulation initiative dummy will be the difference-in-difference estimator. As discussed previously, on the one hand, deregulation occurred gradually and takes time to affect; on the other hand, all deregulation initiatives of my five industries did not happen at the same time. Thus, the industries that had not deregulated at a point in time can be used as control group, and the already deregulated ones at a point in time can be used as test group, thus, the potential confounding effects can be controlled. Intuitively, this model is able to estimate the difference in the level of innovation of firms in deregulated industries before and after the deregulation, compared to this difference for the firms that did not undergo a deregulation during the same period.

3.4 Descriptive Statistics

Table 3.3 summarizes the statistics of the variables used in this paper of full samples as well as the subsamples of deregulated and non-deregulated firms. The whole sample includes the patent and financial information for 9,936 firms, the time period is from 1967 to 2004 and the whole unbalanced panel data consists of 101,355 observations in total. Among these 9,936 firms, 874 are in deregulated industries and 9,062 are in non-deregulated industries. In the sample, firms generating patents are spread broadly across industries (using Fama and French 48 industries classification). In my final sample, a firm in my final sample has 7.24 granted patents per year and each patent receives 2.99 citations[8] on average, which is comparable to previous studies that use similar data sources[9]. A firm in the subsample of non-deregulated industries has 7.42 granted patents per year and each patent receives 2.97 citations on average. A firm in the subsample of deregulated industries has 5.31 patents on average and each patent has 3.22 citations on average. Table 3.4 shows the counts and percentage of firms with and without patents in each industry. The fraction of firms with at least one patent of each industry ranges from 7.4% (banking) to 80.3% (electric). For the five industries that are deregulated, the fraction of firms with at least

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[8] The average citation for each patent is equal to the average citation received by each firm divided by the average patent granted for each firm.

[9] The results are comparable to Fang,Tian and Tice (2010) and Bereskin and Hsu (2013).

one patent of each industry ranges from 27.6% to 43.8%. All industries have at least one firm with at least one patent.

Table 3.3 also shows descriptive statistics of financial characteristics of the whole sample and subsamples. For the whole sample, an average firm is 24.5 years old since its IPO date and has natural logarithm of market value of market of 4.37, ROA of 6%, PPE ratio of 28%, leverage of 23%, Tobin's Q of 1.93, and capital expenditure ratio of 0.06, which is comparable to other studies analyzing the similar panel dataset[10]. For the subsample of non-deregulated industries, a firm is 24 years old on average, its IPO date is counted as the first year. And the firm has natural logarithm of market value of market of 4.27, ROA of 6%, PPE ratio of 26%, leverage of 23%, Tobin's Q of 1.96, capital expenditure ratio of 0.06. For the subsample of deregulated industries, an average firm is 27.7 years old since its IPO date and has natural logarithm of market value of market of 5.46, ROA of 9%, PPE ratio of 53%, leverage of 32%, Tobin's Q of 1.58, capital expenditure ratio of 0.1.

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[10] The results are comparable to Fang,Tian and Tice (2010).

Table 3.3 Descriptive Statistics This sample consists of 101,355 firm-year observations during 1967-2004. Panel A shows the descriptive statistics for all firms in all industries. Panel B reports descriptive statistics for subsample that consist only firms in industries that are not been deregulated. "Patents" is the adjusted number of distinct patents granted by a firm *i* in year *t*. "Citations" is the adjusted number of citations received by a firm *i* in year *t*. Panel C reports descriptive statistics for subsample that consist only firms in deregulated industries.

Panel A: All firms								
Variable	**N**	**Mean**	**Max**	**Min**	**S.D**	**1Q**	**Median**	**3Q**
Patents	101355	7.24	0	452.91	27.77	0	0	2.28
Citations	101355	21.66	0	1111.91	89.67	0	0	1.95
ln_age	101355	3	0	4.03	0.68	2.48	3.04	3.56
ln_mv	101355	4.37	-0.62	10.27	2.14	2.79	4.22	5.84
rdta	101355	0.05	0	0.72	0.09	0	0.01	0.05
ROA	101355	0.06	-2.17	0.4	0.23	0.04	0.12	0.18
ppeta	101355	0.28	0	0.89	0.2	0.12	0.24	0.39
lev	101355	0.23	0	1.37	0.2	0.06	0.21	0.35
capexta	101355	0.06	0	0.35	0.06	0.02	0.05	0.08
Tobin's Q	101355	1.93	0.53	21.2	1.94	0.98	1.3	2.05
Firm size	101355	4.57	-3.17	13.44	2.11	3.08	4.41	5.95
Panel B: Firm in industries that are not deregulated industries								
Patents	93021	7.42	0	452.91	27.88	0	0	2.41
Citations	93021	22.07	0	1111.91	89.31	0	0	2.71
ln_age	93021	2.99	0	4.03	0.67	2.48	3.04	3.56
ln_mv	93021	4.27	-0.62	10.27	2.09	2.73	4.13	5.7
rdta	93021	0.05	0	0.72	0.09	0	0.01	0.06
ROA	93021	0.06	-2.17	0.4	0.24	0.04	0.12	0.18
q	93021	0.26	0	0.89	0.18	0.12	0.23	0.36
lev	93021	0.23	0	1.37	0.2	0.05	0.2	0.34
capexta	93021	0.06	0	0.35	0.05	0.02	0.05	0.08
Tobin's Q	93021	1.96	0.53	21.2	1.97	0.98	1.32	2.1
Firm size	93021	4.45	-3.17	13.44	2.03	3.02	4.3	5.78
Panel C: Firms in industries that are deregulated								
Patents	8334	5.31	0	442.58	26.42	0	0	0
Citations	8334	17.14	0	1086.36	93.51	0	0	0
ln_age	8334	3.09	0	4.03	0.74	2.48	3.26	3.78
ln_mv	8334	5.46	-0.61	10.27	2.37	3.7	5.57	7.23
rdta	8334	0.01	0	0.7	0.04	0	0	0
ROA	8334	0.09	-2.14	0.4	0.19	0.07	0.12	0.17
ppeta	8334	0.53	0	0.89	0.25	0.34	0.59	0.74
lev	8334	0.32	0	1.37	0.21	0.17	0.31	0.44
capexta	8334	0.1	0	0.35	0.07	0.05	0.08	0.14
Tobin's Q	8334	1.58	0.54	19.9	1.44	0.96	1.17	1.62
Firm size	8334	5.93	-2.67	11.74	2.44	4.19	6.08	7.78

Table 3.4 Number of firms with and without patents by industry

This table summarizes the number and percentage of firms in each industry that innovate throughout the sample period of 1967-2004 and the number and percentage of firms in each industry that didn't innovate at all throughout the sample period. The industries are defined according to Fama and French 48 Industry Portfolios.

Panel A: Five deregulated industries						
Industry	FF definition	Firms didn't innovate		Firms have at least one patent		Total number of firms in the subsample
Entertainment	7	79	70.5%	33	29.5%	112
Petroleum and Natural Gas	30	170	62.3%	103	37.7%	273
Utilities	31	63	56.3%	49	43.8%	112
Communication	32	175	70.0%	75	30.0%	250
Transportation	40	92	72.4%	35	27.6%	127
Total number of firms		579		295		874
Panel B: Other industries						
Industry	FF definition	Firms didn't innovate		Firms have at least one patent		Total number of firms in the subsample
Agriculture	1	17	45.9%	20	54.1%	37
Food Products	2	85	45.2%	103	54.8%	188
Candy & Soda	3	15	88.2%	2	11.8%	17
Beer & Liquor	4	20	60.6%	13	39.4%	33
Tobacco Products	5	4	30.8%	9	69.2%	13
Recreation	6	47	35.6%	85	64.4%	132
Printing and Publishing	8	31	52.5%	28	47.5%	59
Consumer Goods	9	77	30.0%	180	70.0%	257
Apparel	10	70	50.4%	69	49.6%	139
Healthcare	11	111	81.0%	26	19.0%	137
Medical Equipment	12	99	20.9%	374	79.1%	473
Pharmaceutical Products	13	147	23.4%	482	76.6%	629
Chemicals	14	58	26.7%	159	73.3%	217

Rubber and Plastic Products	15	39	26.2%	110	73.8%	149
Textiles	16	42	44.7%	52	55.3%	94
Construction Materials	17	94	35.7%	169	64.3%	263
Construction	18	56	62.9%	33	37.1%	89
Steel Works Etc	19	45	29.4%	108	70.6%	153
Fabricated Products	20	18	30.5%	41	69.5%	59
Machinery	21	93	20.0%	372	80.0%	465
Electrical Equipment	22	38	19.7%	155	80.3%	193
Automobiles and Trucks	23	47	24.7%	143	75.3%	190
Aircraft	24	13	24.5%	40	75.5%	53
Shipbuilding, Railroad Equipment	25	10	40.0%	15	60.0%	25
Defense	26	5	23.8%	16	76.2%	21
Precious Metals	27	28	68.3%	13	31.7%	41
Non-Metallic and Industrial Metal Mining	28	22	51.2%	21	48.8%	43
Coal	29	9	64.3%	5	35.7%	14
Personal Services	33	56	70.9%	23	29.1%	79
Business Services	34	827	59.4%	566	40.6%	1393
Computers	35	226	37.7%	374	62.3%	600
Electronic Equipment	36	158	21.7%	570	78.3%	728
Measuring and Control Equipment	37	65	21.2%	241	78.8%	306
Business Supplies	38	29	20.1%	115	79.9%	144
Shipping Containers	39	9	23.1%	30	76.9%	39
Wholesale	41	198	65.3%	105	34.7%	303
Retail	42	327	83.4%	65	16.6%	392
Restaraunts, Hotels, Motels	43	123	87.2%	18	12.8%	141
Banking	44	175	92.6%	14	7.4%	189
Insurance	45	109	87.2%	16	12.8%	125
Real Estate	46	66	89.2%	8	10.8%	74
Trading	47	160	82.5%	34	17.5%	194
Other	48	98	57.0%	74	43.0%	172
Total number of firms		3966		5096		9062

Chapter 4

EMPIRICAL RESULTS

4.1 Time Series Analysis

In this section, I will analyze the time series of the total number of patents in the aggregate industry level produced by all firms in deregulated industries and by all firms in non-deregulated industries. I also analyze the financial characteristics in the aggregate industry level of all firms in deregulated industries and all firms in non-deregulated industries separately.

4.1.1 Time series analysis for the patent counts and citation counts

Figure 4.1 displays the time series of the total number of patents and total number of citations of firms in all the Famma-French 48 industries, subsamples of firms in deregulated industries and subsamples of firms in non-deregulated industries. The trend line in Panel A displays that the aggregate level of patents of the full sample steadily increases from the year 1970 to the year 1975. In 1976 the patents counts decreas slightly and then begin to increase until 1979. From 1980 to 1982, the aggregate level of patents doesn't change a lot, but the patents counts begin to decrease from 1983 to 1987. The aggregate level of patents steadily increases from1988 to 2002.

Panel B shows us the different time trends for subsamples of deregulated and non-deregulated industries during the same time period. Deregulated industries generate more patents than non-deregulated industries in aggregate during the period of 1970-1974. The patent counts of deregulated industries decrease suddenly in 1975, while the patent counts of non-deregulated industries increase steadily. From 1976 to 1979 the patent counts of deregulated industries keep increasing. Although the non-deregulated industries generate more patents than before, the deregulated industries still generate more patents than the non-deregulated industries. However, since 1980, the patent counts of deregulated industries begin to decrease, and the patent counts of non-deregulated industries exceed that of deregulated industries in 1982 for the first time. And after 1982, the patent counts of deregulated industries keep fluctuating but never exceed that of non-deregulated industries again. From 1989 to 2002, the patent counts of non-deregulated industries keep increasing. From Panel A and Panel B, it can be tell that, before 1976, deregulated industries contribute more to the increase of the patent counts, while after 1976, the non-deregulated industries contribute more. 1976 is the year when the very first significant economic deregulation initiated to Transportation industry.

Panel C and Panel D describe how the number of citations of the full sample, subsample of deregulated industries and subsample of non-deregulated industries change during the sample period 1967-2004. For the full sample, the number of citations increases from 1967 to 1975. After 1975, it fluctuates with a trend toward decreasing, which may be caused by the time truncation problem. Similarly to the situation of number of patents, patents of deregulated industries receive more citations than patents of non-deregulated industries in aggregate during the period of 1970-1974.After 1975, the number of citations received by patents of non-deregulated industries exceeds that of deregulated industries.

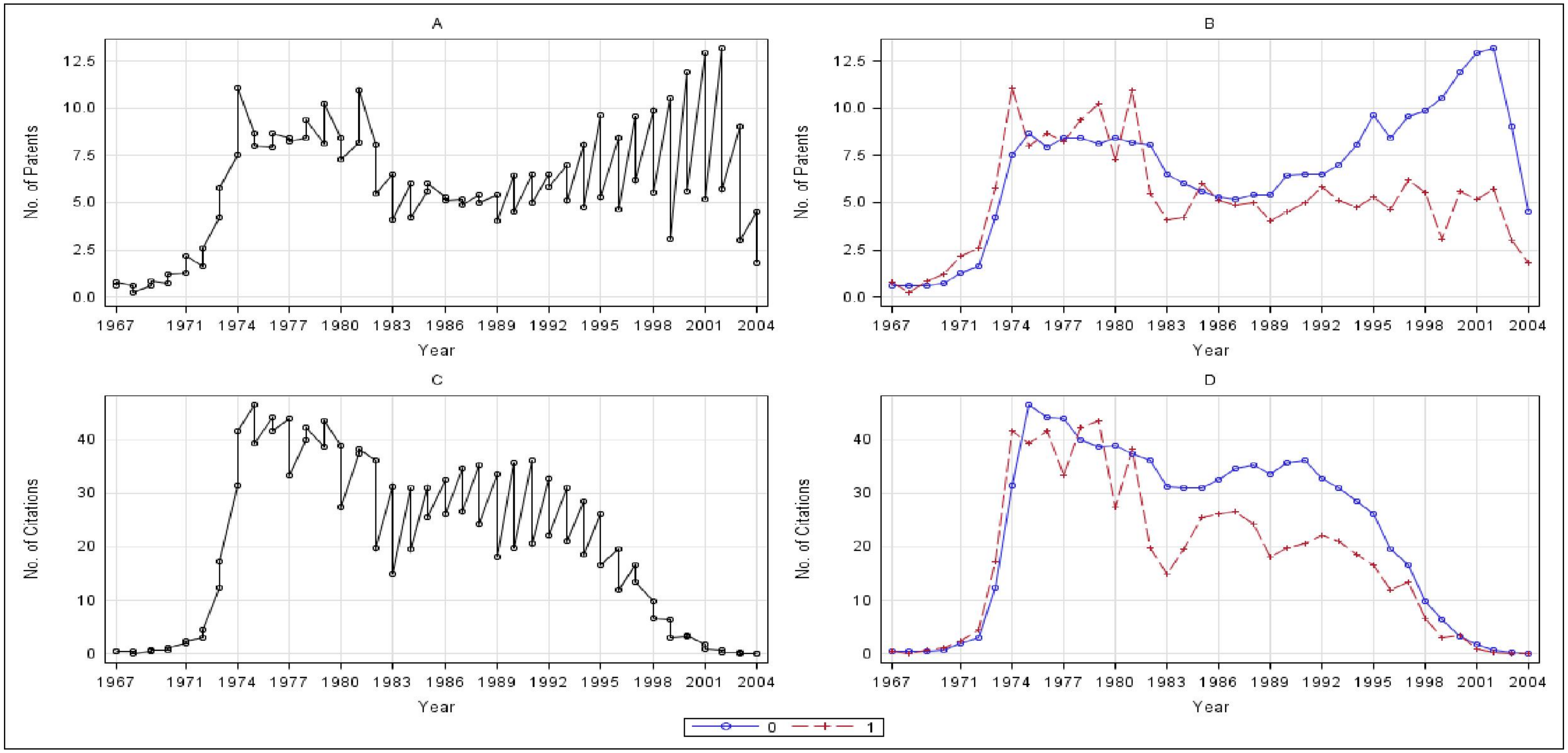

Figure **4.1** **Time series of patent counts and citation counts for full sample, subsample of firms in deregulated industries and subsample of firms in non-deregulated industries 1967-2004.** Panel A and Panel C presents the aggregate level of patents and citations of the full sample across sample period. Panel B and Panel D presents different time trends of patents and citations for subsamples of deregulated and non-deregulated industries during the same time period. The solid blue line (0) indicates trend for firms in non-deregulated industries, the red dashed line (1) indicates trend for firms in deregulated industries

4.1.2 Time series analysis of financial characteristics of firms in subsample of deregulated industries and in subsample of non-deregulated industries

Figure 4.2 shows the time series of the financial characteristics in the aggregate industry level for all firms in deregulated industries and all firms in non-deregulated industries separately. Blue lines track firms in non-deregulated industries, while red lined lines track firms in deregulated industries. Panel A indicates that the average firm size in deregulated industries is larger than the average firm size in non-deregulated industries, but deregulated firms grow a little slower than their counterparts. This is consistent with the fact that all my five deregulated industries are monopolies or oligopolies in natural. Both groups of firms experience a decline in profitability (ROA) following deregulation, but the decline of non-deregulated firms is a little more significant. The leverage levels of both groups are reduced following the deregulation, and the decrease of non-deregulated industries is a little more significant. This means that the deregulation pushes firms toward lower leverage. Evidence also shows that, following deregulation, the market value of firms of both groups increase, while the average market value of firms in deregulated industries is larger than the market value of firms in non-deregulated industries. Capital expenditure (CAPEXTA) and asset tangibility (PPETA) of firms in both groups in Panel E decrease following deregulation, although the values of deregulated firms have a higher level than that of non-deregulated firms. The research and development expenditures-to-assets ratio (RDAT) of deregulated firms in Panel G increases, although to a much lower level than that of non-deregulated firms. Panel H shows evidence that the growth opportunities (Tobin's Q): the level of non-deregulated firms' Q is above the level of deregulated firms' Q through the sample period, but the growth opportunities of firms in deregulated industries are improved after deregulation. Finally, the HHI value of deregulated industries in Panel I decreases more significantly that of non-deregulated industries, which shows that the market of deregulated industries becomes more competitive after deregulation. These results are closely consistent with other studies analyzing large panels of firm financial characteristics (Ovtchinnikov, 2010; Atanassov,nanda and Seru,2005). According to the tradeoff theory, after economic deregulation, the composition of industries changes and the industries become more competitive. A decline in profitability, an increase in growth opportunities and a decline in asset tangibility increase the expected bankruptcy and agency cost of free cash flow, which push firms to lower leverage to control underinvestment problems (Ovtchinnikov, 2010).

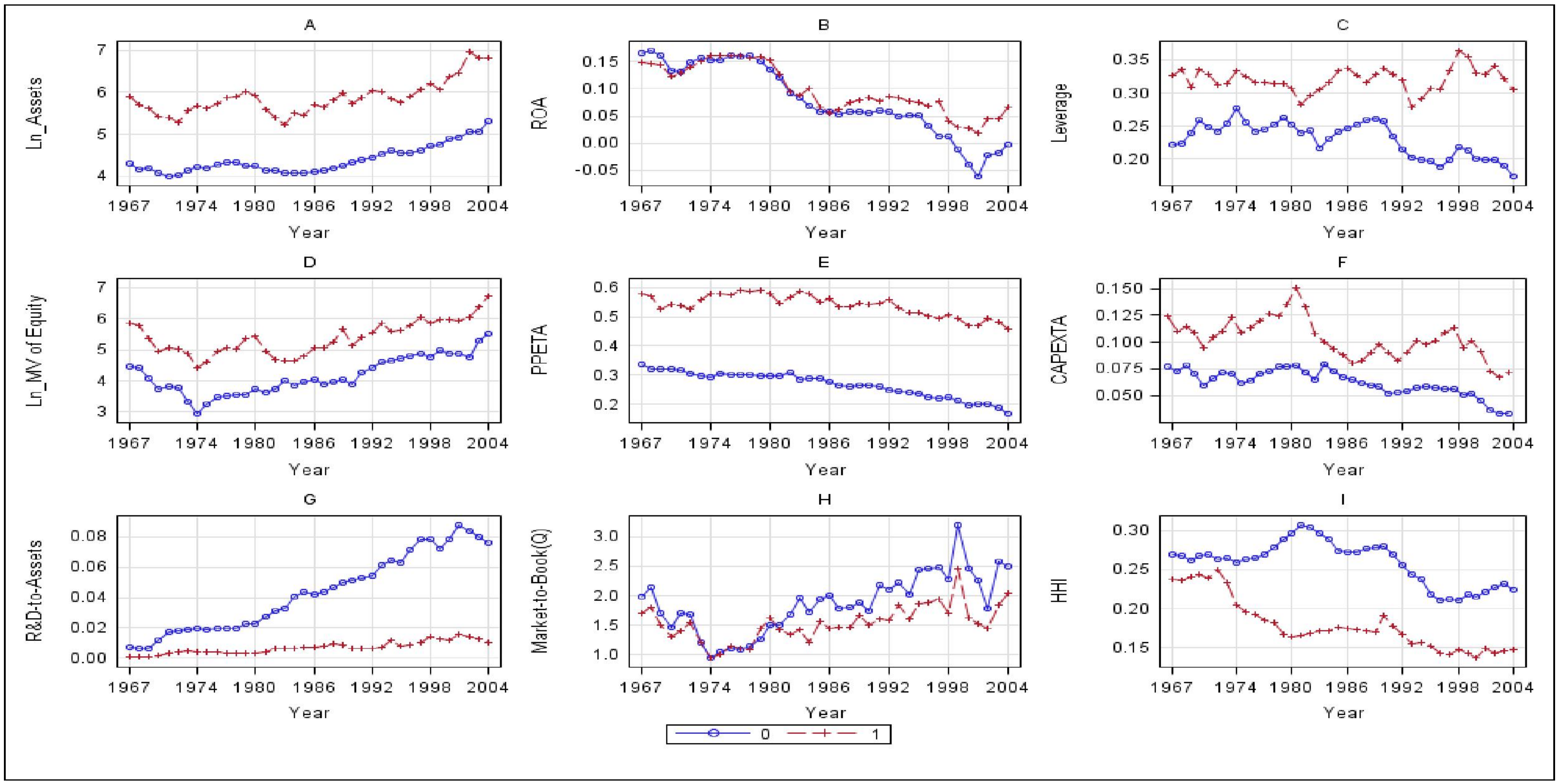

Figure 4.2 **Time series of firm financial characteristics for firms in non-deregulated and deregulated industries, 1967-2004.** The blue line (0) indicates trend for firms in non-deregulated industries, the red line (1) indicates trend for firms in deregulated industries.

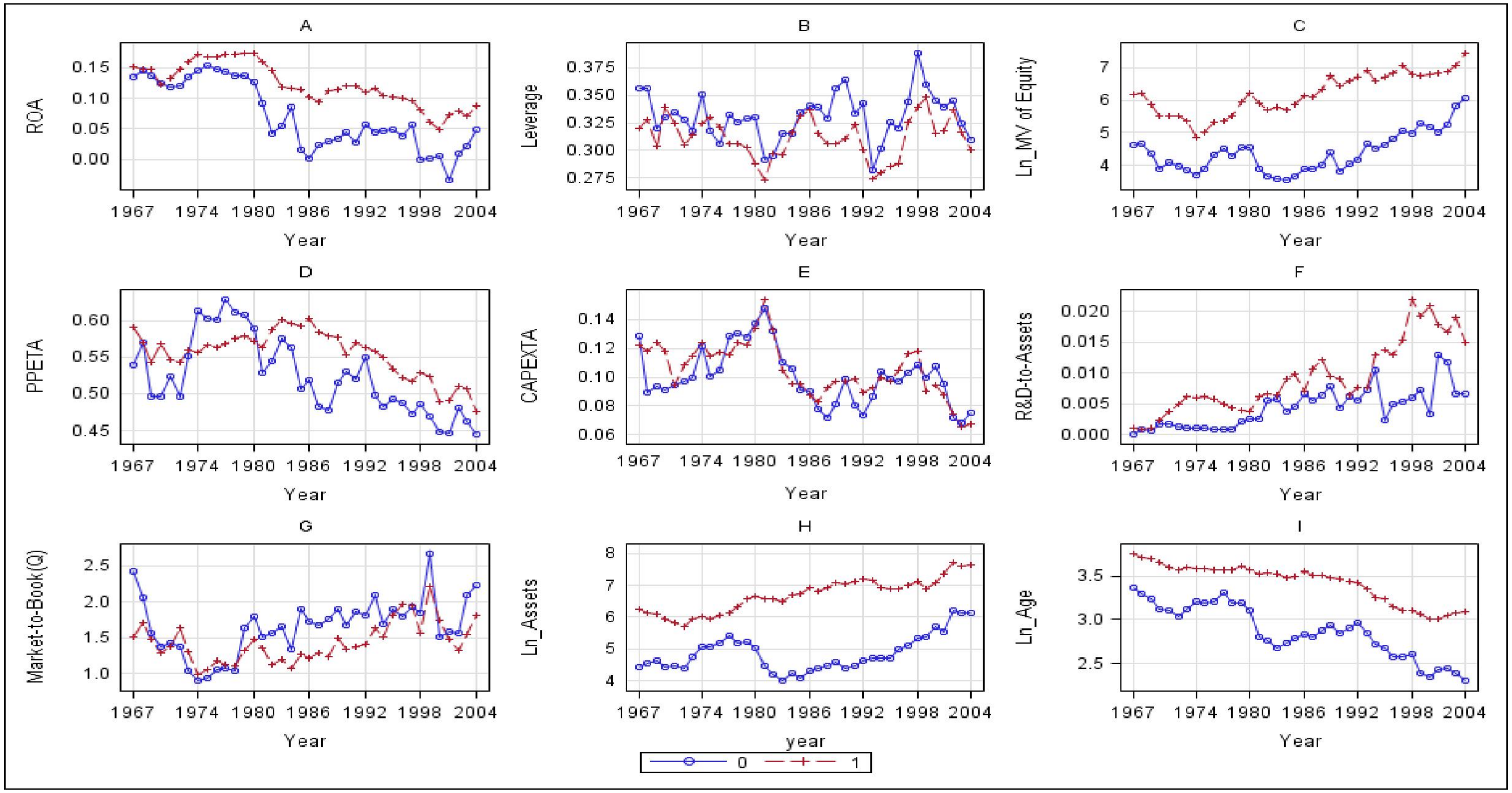

Figure 4.3 **Time series of firm financial characteristics for innovating firms and non-innovating firms in deregulated industries, 1967-2004.** The solid blue line (0) indicates trend for non-innovating firms, the red dashed line (1) indicates trend for innovating firms.

4.2 Difference-in-Difference Analysis

I focus my empirical analysis on patenting activity by US public firms in my five deregulated industries. As discussed before, the deregulation influences the competition environment of the industry, through which it shocks the operating environment of firms. First, I conduct the following difference-in-difference estimation to test whether the competition environment changes after economic deregulation has a significant impact on the innovation behavior of the firms. The results are shown in Table 4.1.

The baseline econometric model focuses on the relationship between indicator dummies for deregulations and the proxies for the quantity and quality of innovation of firms, and the difference-in-difference method, which estimates the difference in the level of innovation in firms of deregulated industries before and after the deregulation, compared to this difference for firms that didn't undergo a deregulation during the same period. By including the year fixed effects and the industry fixed effects, the hypothesized effect of deregulation on innovation is identified and isolated from secular time trends for each industry. The baseline model, which is a fixed effect model, is estimated as follows:

$$Y_{it} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it}$$

where *i* and *t* index firms and years, Y_{it} is one of the five dependent variables measured of firm *i* in year *t* and X_{it} is a set of year *t* control variables from Table 3.2. $Deregtime_{it}$ is the deregulation dummy set to one if the firm operates in the year when the first deregulation initiative to its industry is adopted , and $Deregind_{it}$ captures the deregulation treated group, which is set to one if the particular firm belongs to one of my five deregulated industry, to zero if the particular firm belongs to non-deregulated industry. ϑ_t is year fixed effect. γ_j is industry fixed effect. Any shocks in innovation coinciding with the timing of deregulation (which varies from industry to industry) are controlled for using the time fixed effects and industry fixed effects. The inclusion of industry fixed effects ensures that any differential pre-trends in innovation in the treatment group and control group are stripped out. ε_{it} is a random error term. The difference-in-difference coefficient is β_2, which measures differences in the innovation behavior of deregulated and non-deregulated firms, thus it captures the effect of deregulation on firms' innovation activities.

First, I examine the effect of deregulation on innovation quantity by setting the innovation quantity proxies as dependent variable and estimated the following model:

$$LnPCounts_{i,t+1}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (1a)$$

$$LnPCounts_{i,t+2}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (2a)$$

$$LnPCounts^{a}_{i,t+3} = \alpha + \beta_1 Deregind_{it} + \beta_2(Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (3a)$$

$$LnPCounts3yr^{a}_{it} = \alpha + \beta_1 Deregind_{it} + \beta_2(Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (4a)$$

$$LnPCounts5yr^{a}_{it} = \alpha + \beta_1 Deregind_{it} + \beta_2(Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (5a)$$

Table 4.1 **Difference-in-difference estimation of the effects of deregulation on firm innovation level measured by the number of patents filed, 1967-2004.** The full sample consists of 101,355 observations. The table presents difference-in-difference estimations of the parameters from two-way fixed effects Ordinary Least Squares regressions of number of patents filed by firms on its determinants. Column (1)-(5) represents results corresponding to Equation (1a)-(5a), respectively. Definitions for variables are listed in Table 4.2. Year fixed effects and industry fixed effects are included in all five regression, but the estimations are not presented. Both coefficient estimates and standard errors are reported. Significant at *** 1%, **5% and *10%.

	(1a)		(2a)		(3a)		(4a)		(5a)	
Depdent Variables	$LnPCounts^{a}_{i,t+1}$		$LnPCounts^{a}_{i,t+2}$		$LnPCounts^{a}_{i,t+3}$		$LnPCounts3yr^{a}_{it}$		$LnPCounts5yr^{a}_{it}$	
	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*
Deregind*Deregtime	-0.126***	0.031	-0.133***	0.032	-0.131***	0.033	-0.173***	0.041	-0.142***	0.047
Deregind	-0.415***	0.048	-0.467***	0.051	-0.519***	0.054	-0.663***	0.065	-0.909***	0.077
ROA	-0.195***	0.020	-0.148***	0.022	-0.118***	0.025	-0.136***	0.030	-0.081**	0.039
Ln_age	0.160***	0.006	0.176***	0.007	0.192***	0.008	0.208***	0.010	0.240***	0.013
Ln_mv	0.295***	0.002	0.307***	0.002	0.320***	0.002	0.420***	0.003	0.489***	0.003
RDTA	0.161***	0.053	0.167***	0.058	0.185***	0.064	0.291***	0.078	0.380***	0.101
PPETA	-0.119***	0.026	-0.124***	0.028	-0.124***	0.030	-0.192***	0.037	-0.220***	0.045
LEV	0.089***	0.019	0.059***	0.020	0.053**	0.022	0.024	0.026	-0.011	0.033
CAPEXTA	0.166***	0.076	0.245***	0.081	0.280***	0.086	0.250**	0.104	0.253**	0.126
Q	-0.047***	0.002	-0.046***	0.002	-0.049***	0.002	-0.064***	0.003	-0.077***	0.004
HINDEX	-0.022	0.071	-0.015	0.075	0.044	0.080	0.068	0.098	0.073	0.118
HINDEX2	0.084	0.089	0.059	0.095	-0.034	0.101	-0.028	0.123	-0.064	0.147
Intercept	-1.759***	0.039	-1.767***	0.041	-1.978***	0.044	-1.872***	0.054	-1.897	0.068
Year & industry FE	Included		Included		Included		Included		Included	
No. of Obs. Used	93183		85284		77951		77933		64676	
R2	0.36		0.37		0.37		0.42		0.45	

I estimate Eq. (1a) to (5a) using fixed effects OLS regression. Table 4.1 reports the fixed effects OLS regression results. The dependent variables capture corporate innovation quantity: the natural logarithm of one plus the number of patents applied (finally granted) in year *t+1*, *t+2* and *t+3* respectively and the natural logarithm of cumulative number of patents applied in the following 3 and 5 years respectively . The reason for this setting is that the innovation process generally takes longer than one year and the deregulation affects the innovation behavior with year lags too. The interaction term between the deregulated group dummy and deregulation treated dummy is the coefficient of interest.

First, the difference-in-difference coefficients are negative and significant at 1% level in all five columns, implying that, following deregulation, the introduction of competition in the market has had a negative impact on firms in five deregulated industries compared to firms in non-deregulated industries. Second, the coefficient of the group dummy is negative and significant, indicating that firms in deregulated industries have a lower number of patents when compared to firms in non-deregulated industries, holding all else constant. Third, the coefficients of deregulation dummies do not change significantly but with small fluctuations across columns (1a) to (5a). This pattern is repeated on each of the five dependent variables that I employ in Table 4.1.

Quantitatively, the magnitude of deregulation dummies from column (1a) to (3a), which use the natural logarithm of one plus the number of patents filed in one, two and three years as dependent variable, have the similar pattern, however, are somewhat different. The negative coefficient in column (1a) suggests that innovation activities of firms in the first year following in deregulated industries declines 12% compared to firms in non-deregulated industries, the number of patent applied in the second year following the deregulation of deregulated firms declines more at 13.3%, which implies that the effect of deregulation on innovation activities becomes stronger as time passing. However, in the third year following the deregulation, the patents applied by deregulated firms decrease about 13.05% compared to patents applied by non-deregulated firms, and the effect of deregulation becomes weaker. Thus, the time dynamic effect of deregulation is obvious. In columns (4a) to (5a), I replace the dependent variable with the natural logarithm of the cumulative number of patents filed in three and five years, respectively. The difference-in-difference coefficient estimates are negative and significant at the level of 1% also. Following deregulation, firms in deregulated industries generated 17.3% fewer patents in the subsequent three years post deregulation than firms in non-deregulated industries three years after deregulation. And firms in deregulated industries generated 14.2% fewer patents in the subsequent five years post deregulation than firms in non-deregulated industries five years after deregulation. Again, the effects of deregulation become weaker when time becomes longer.

Overall, the results in Table 4.1 support the hypotheses. Deregulation significantly negatively affects the level of innovation activities of firms in deregulated industries compared to non-deregulated firms.

Table 4.1 focuses solely on the magnitude quantity of innovations. Quantity is one of the criteria to measure how well a firm innovates. However, quantity alone is not sufficient to value the innovation activity of a firm. When investigating the innovation activity of a firm, we should not only consider the quantity of the patent but also the quality of the patent. What can help a firm out from the competition is not only quantity of the innovation, but also the quality of the innovation. A bunch of patents with low quality are meaningless to a firm. Thus, a positive impact of any external shock should improve both the quantity and quality of innovation activity. Thus, next I will investigate how the economic deregulation influences the innovation quality by replacing the dependent variable with innovation quality proxies, the natural logarithm of patent citations, and estimate the following difference-in-difference models:

$$LnCCounts_{i,t+1}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (1b)$$

$$LnCCounts_{i,t+2}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (2b)$$

$$LnCCounts_{i,t+3}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (3b)$$

$$LnCCounts3yr_{it}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (4b)$$

$$LnCCounts5yr_{it}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2(Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (5b)$$

Table 4.2 reports the two-way fixed effects OLS regression results of Eq. (1b) to (5b). The dependent variables capture corporate innovation quality: the natural logarithm of one plus the number citation received by firm *i* in year *t+1*, *t+2* and *t+3* and the natural logarithm of one plus the cumulative number citation received by firm *i* in the subsequent 3 and 5 years, respectively. The patterns of the results are different from that of the number of patent counts. Firstly, the difference-in-difference coefficients are statistically negative and significantly at 1% level for all the five equations. The strong negative coefficients imply that, following deregulation, the innovation quality of deregulated industries declines compared to non-deregulated industries. In other words, after the deregulation, patents generated by deregulated industries become less general and the deregulated firms may focus on a narrower set of innovations than before (citations are negatively affected). Second, firms in deregulated industries have a lower number of citations when compared to firms in non-deregulated industries, holding all else constant. This result shows that, on average, the deregulated firms' patent quality is lower than the patent quality of non-deregulated firms. Third, the coefficients of deregulation dummies do not change significantly across columns (1b) to (5b). This pattern is repeated for each of the five dependent variables that I employ in Table 4.2 Panel B, but it is different from the pattern of patent quantity.

Quantitatively, the magnitude of deregulation dummies from column (1b) to (3b) suggests how the quality changes following deregulation. The negative coefficient in column (1a) suggests that, in the first year following deregulation, patent quality of firms in deregulated industries declines 11.7% compared to firms in non-deregulated industries. Different from the rate of decline in the number of patents, the rate of decline in citations keeps increasing in the following 2 and 3 years, with 21.6% and 33.1% sequently, which implies that the effect of deregulation on innovation quality becomes stronger as time passes. A similar pattern is shown in columns (4b) and (5b) when I replace dependent variables with the natural logarithm of cumulative number of citations received by firms in three and five years, respectively.

One may argue that, in a deregulation environment, of the negative effect of deregulation, a deregulated firm innovates less than before, so, in turn, it applied fewer patents. Logically, with fewer patents applied, the total citations received by the firm's patent portfolio should be fewer, which is simply a result of declining number of patents but not the effect of deregulation. However, according to the results in Table 4.2, the decline rate of citations ranges from 11.7% to 53.7%, while the decline rate of number of patents ranges from 12.6% to 17.3%. The rate of decline in citations is greater than the rate of decline in the number of patents. Thus, the concern should be alleviated and a decline in total number of citations should be a true indicator of innovation quality decline. Deregulation should responsible for at least part of the decline in innovation quality. Following deregulation, when the industry becomes more competitive, firms in the deregulated industries have to adjust their R&D

strategy to react against the new stressful situation. These strategies might include controlling cost, shortening the innovation cycle, taking less risky action and focusing on narrow previous knowledge and not to explore other fields. All of these possible strategies taken by the firms would in turn adversely affect the citation amount of the whole patent portfolio of a firm.

Table 4.2 Difference-in-difference estimation of the effects of deregulation on firm innovation quality measured by the number of citation received, 1967-2004. The full sample consists of 101,355 observations. The table presents difference-in-difference estimations of the parameters from two-way fixed effects Ordinary Least Squares regressions of number of patents filed by firms on its determinants. Column (1b)-(5b) represents results corresponding to Equation (1a)-(5a), respectively. Definitions for variables are listed in Table 4.2. Year fixed effects and industry fixed effects are included in all five regression, but the estimations are not presented. Both coefficient estimates and standard errors are reported. Significant at *** 1%, **5% and *10%.

Depdent Variables	(1a)		(2a)		(3a)		(4a)		(5a)	
	$LnCCounts_{i,t+1}{}^{a}$		$LnCCounts_{i,t+2}{}^{a}$		$LnCCounts_{i,t+3}{}^{a}$		$LnCCountsNext3yr_{it}{}^{a}$		$LnCCountsNext5yr_{it}{}^{a}$	
	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*
Deregind*Deregtime	-0.112***	0.043	-0.216***	0.044	-0.332***	0.046	-0.323***	0.056	-0.537***	0.063
Deregind	-0.541***	0.068	-0.510***	0.072	-0.458***	0.076	-0.694***	0.091	-0.767***	0.107
ROA	0.150***	0.028	0.247***	0.031	0.283***	0.035	0.436***	0.042	0.506***	0.054
Ln_age	0.396***	0.009	0.461***	0.010	0.526***	0.011	0.582***	0.013	0.691***	0.017
Ln_mv	0.238***	0.003	0.242***	0.003	0.244***	0.003	0.334***	0.004	0.410***	0.004
RDTA	0.185***	0.075	0.187***	0.083	0.197***	0.092	0.331***	0.110	0.418***	0.140
PPETA	-0.105***	0.037	-0.072*	0.040	0.001	0.043	-0.149***	0.052	-0.273***	0.062
LEV	0.002	0.026	-0.036	0.029	-0.050	0.031	-0.065*	0.037	-0.045	0.046
CAPEXTA	0.197***	0.106	0.185***	0.113	0.165***	0.121	0.207***	0.145	0.209***	0.173
Q	-0.060***	0.003	-0.061***	0.003	-0.066***	0.003	-0.087***	0.004	-0.108***	0.005
HINDEX	0.122	0.101	0.162	0.107	0.257*	0.115	0.203	0.138	0.245	0.164
$HINDEX^2$	0.117	0.127	0.082	0.135	-0.029	0.144	0.183	0.173	0.115	0.204
Intercept	-1.739***	0.049	-1.944***	0.053	-2.174***	0.058	-2.285***	0.069	-2.578***	0.086
Year & industry FE	Included		Included		Included		Included		Included	
No. of Obs. Used	93183		85284		77951		77933		64676	
R2	0.23		0.23		0.24		0.29		0.33	

4.3 The Dynamic Effects of Economic Deregulations Analysis

Both economic regulation and deregulation are often driven by lobbyists and lobbying groups that represent various industries and business interests. The success in getting the statutes adopted directly depends on commonly changing economic prospects for the firms lobbying together (Bertrand and Mullainathan, 2003). As discussed above, although the economic deregulation represents an exogenous shock to the industry competition, the industry level factors that manifested differently across industries could have affected the timing of deregulation in different industries (Kroszener and Strahan, 2013). If this is the case, a reverse causal relationship between deregulation and innovation presents. In order to explore the possibility of reverse causality, I follow Bertrand and Mullainathan (2003) to investigate the dynamic effects of economic deregulation on innovation behaviors. If the deregulation policy was passed in response to changing economic conditions, one might expect an "effect" of the deregulation even prior to its passage.

To investigate the temporal dynamics, I introduce four timing dummies corresponding to four time periods around deregulations for each industry. $Dereg^{-2}$ is a dummy variable set to one for all years up to and including two years prior to the year the first significant deregulatory initiative is adopted for each industry. I define the $Dereg^{-2}$ period as the regulated or pre-deregulation period. $Dereg^{0}$ is set to one the year the first significant deregulatory initiative is adopted for each industry. $Dereg^{3}$ is set to one for the three-year period immediately following the year when the first deregulatory initiative is adopted. I define the Dereg^{3} period as the first post-deregulation period or partial deregulation period. Dereg^{p3} is set to one for the three-year period immediately following the year when the last deregulatory initiative is adopted. I define the Dereg^{p3} period as the second post-deregulation period or complete deregulation period.

I estimate the following model:

$$
\begin{aligned}
LnPCounts_{i,t}^{a} = \alpha &+ \beta_1 Dereg_{it}^{-2} \times Deregind_{it} + \beta_2 Dereg_{it}^{0} \times Deregind_{it} \\
&+ \beta_3 Dereg_{it}^{3} \times Deregind_{it} + \beta_3 Dereg_{it}^{p3} \times Deregind_{it} + \beta_4 X_{it} \\
&+ \beta_5 Deregind_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \qquad (6)
\end{aligned}
$$

$$
\begin{aligned}
LnCCounts_{i,t}^{a} = \alpha &+ \beta_1 Dereg_{it}^{-2} \times Deregind_{it} + \beta_2 Dereg_{it}^{0} \times Deregind_{it} \\
&+ \beta_3 Dereg_{it}^{3} \times Deregind_{it} + \beta_3 Dereg_{it}^{p3} \times Deregind_{it} + \beta_4 X_{it} \\
&+ \beta_5 Deregind_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \qquad (7)
\end{aligned}
$$

Table 4.3 reports the dynamic effect of deregulation on number of patents and number of citations. The coefficients of Dereg^{-2} are all insignificant in the 1% level, indicating that firm level innovation activities and the innovation quality show no significant changes two years prior to deregulation. In other words, the innovation activities of deregulated firms are not significantly affected prior to deregulation and the concerns about reverse causality should be alleviated.

The coefficients for Dereg^{0}, Dereg^{3} and Dereg^{p3} are all negative and significant, consistent with the baseline findings. The results also show that the effect of deregulation on the level and quality of innovative activity increases during the partial deregulation period. However, the declining rate of number of citations decreases during the complete deregulation period while the declining rate of the number of patents keeps increasing during the complete deregulation period. This result indicates that the effects of deregulation is manifested in the first year of deregulation and enlarged in the following years; however, when the industry was completed deregulated, the adverse effects of deregulation on innovation activity become diminishing.

Table 4.3 Dynamic effects of economic deregulation on number of patents applied by firms and number of citations received during sample period 1967-2004. This table investigates the temporal dynamics and reverse causality problem. $Dereg^{-2}$ is a dummy variable set to one for all years up to and including two years prior to the year first significant deregulatory initiative is adopted for each industry. I define the $Dereg^{-2}$ period as the regulated period. $Dereg^{0}$ is set to one the year the first significant deregulatory initiative is adopted for each industry. $Dereg^{3}$ is set to one for the three-year period immediately following the year when the first deregulatory initiative is adopted. $Dereg^{p3}$ is set to one for the three-year period immediately following the year when the last deregulatory initiative is adopted. Difference-in-differences estimations of the parameters from two-way fixed effects Ordinary Least Squares regressions are presented. Year fixed effects and industry fixed effects are included in all five regression, but the estimations are not presented. Both coefficient estimates and standard errors are reported. Significant at *** 1%, **5% and *10%.

Depdent Variables	(1)		(2)	
	$LnPCounts_{i,t}{}^{a}$		$LnCCounts_{i,t}{}^{a}$	
	Coef.	*Std.Er.*	Coef.	*Std.Er.*
$Dereg^{-2}$*Deregind	0.113	0.036	-0.024	0.039
$Dereg^{0}$ *Deregind	-0.013^{*}	0.045	-0.137^{***}	0.052
$Dereg^{3}$ *Deregind	-0.079^{**}	0.031	-0.279^{***}	0.041
$Dereg^{p3}$ *Deregind	-0.190^{***}	0.030	-0.198^{***}	0.039
Year & industry FE	Included		Included	
No. of Obs. Used	101355		101355	

4.4 Channels

Additionally, a firm's innovation may be influenced by firm characteristics. Thus, I also control for a group of firm characteristics which may affect the firm's innovation activities. In this section I focus on the firms in five deregulated industries and try to illustrate the channels through which the deregulation affects the firms' innovation behavior. The subsample used in this section includes all firms in all five deregulated industries. And I estimated the effect of deregulation on the innovation behavior of these firms by focusing on the number of patents granted to each the firm in each year. I model the number of patents applied by firms as follows:

$$LnPCounts_{i,t}^{a} = \alpha + \beta_1 Deregtime_{it} + \beta_2 X_{it} + \beta_3 Deregtime_{it} \times X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (8)$$

where the dependent variables capture corporate innovation quantity: the natural logarithm of one plus the number of patents applied (finally granted) in year *t*, $Deregtime_{it}$ is the deregulation dummy, X_{it} is a group of firm financial characteristics including: ROA (return on assets ratio), Leverage ratio (debt-to-asset ratio), R&D expenditures-to-assets ratio, PPE-to-assets ratio, Capital, Tobin's Q ,the natural logarithm of book value assets, the Herfindahl Index, the squared Herfindahl and the firm age. Variable definitions are described in detailed in Table 3.2. ϑ_t is the year fixed effect and γ_j is the industry fixed effect. $Deregtime_{it} \times X_{it}$ is the interaction term between the deregulation dummy and a vector of the financial characteristics of the firm, which is used to show how the financial characteristics affect innovation behaviors following deregulation.

Table 4.4 Panel A reports the results for the sample consisting of all firms in the five deregulated industries. To address the concern that the results may be driven by a large number of firm-year observations with zero patents, I restrict the sample to firms in all of the five deregulated industries that have at least one patent during the sample period 1967-2004, and the results of this subsample are reported in Table 4.4

Panel B. The results are similar in sign and significance across the two samples, thus I focus on discussing the results in Tale 4.4 Panel A.

The deregulation itself leads to a 19.4% decline in the number of patents applied for by deregulated firms. One possible reason is that price deregulations alter industry profits, hence the incentives to innovate. During the regulated period, the firms could pass on most of the costs to the final customers through the regulated retail price. However, following the price deregulation, most of the costs can't be passed on to customers. Reacting to the new situation, firms may dramatically reduce their budget on R&D and change their strategies to do investment and to spend the budget. The strategies include controlling cost, taking on less risky innovation projects, and buying technology from other firms. Thus, the strategy changes will not only influence the firm itself, but also influence the innovation and operating strategy of other firms in related industries, which is actually a kind of multiplier effect to the whole economy. For example, after the Energy Policy Act in 1992, the profitability of the incumbent utility companies declined due to the pricing of electricity to consumers becoming more competitive compared to the high, regulated rate. The decline in profitability reduced the buying power of technology and lowered the demand for the technological innovation (Sanyal and Ghosh, 2013). Granderson(1999) finds that regulation led firms to adopt technology. Rate-of-return affects a firm's input demands for producing its selected output level, and the firm might chose a technology that leads to overcapitalization (Averch and Johnson, 1962). Thus, deregulation may correct the firm's overcapitalization problem and investment incentives, which in turn adversely affects the firm itself and the industry's innovation activity.

The effect of age of the firm on innovation is negative and insignificant before regulation, but becomes positive and significant after deregulation. The result indicates that following deregulation older firms innovate more. But the magnitude of the effect is relatively small, a 1% raise in the age of the firm only increases the innovation by 0.14%. During the regulated period, there are high entry barriers and few new firms in the industry. Thus the age of the firm is not important in explaining the innovation activities. However, after deregulation, new entrants threaten the existing "old" firms. The "old" firms will probably choose to innovate their way out of the competition and maintain their market share. And for the new entrants, if they want to beat their peers, they have to innovate too. This is the result of the "escape effect" defined by Aghion,Bloom,Blundell,Griffith and Howitt(2005).

The effects of ROA, which is an indicator of a firm's profitability, are positive and significant before and after deregulation. Firms always try to maximize profit. The more profit they earn, the more they are able to invest in innovation and the stronger buying power they have. The numbers in Table 4.4 shows that a 1% decline in ROA will decrease innovation by 1.5%. From the statistical analysis in Section 3.1, I observe that ROA declines 3% on average through the sample period 1967-2004 for deregulated firms. Thus, after deregulation the decrease of ROA is responsible for about 4.5% of the innovation decrease. One possible reason for this is that the prices of deregulation and entrance deregulation introduce more competitors to the market and the price for the products is changed to be more competitive, compared to the regulated price. This in turn reduces the profits of the incumbent firms. This is the negative Schumpeterian effect. According to Schumpeter (1942), enhanced market competition reduces the monopoly rents that reward new innovation. In turn, it negatively affects technological progress, which is also called “competition effect”.

Additionally, the more market value the firm has, the more innovation it explores. After deregulation, firms with more tangible assets innovate more. The leverage level of the firm does not have a significant effect on innovation activity following deregulation. The results show that after deregulation the magnitude of the effect of the market value of the firm on innovation decreases but overall it has a 0.14% positive effect on firm innovation activity. Once the market value of the firm increases by 1%, the innovation will increase by 0.14%. Through the sample period, the market value of firms increases 3% on average, which is responsible for a 0.42% increase in innovation. The results in this section consistent with the prediction of Aghion (2005): when the competition is high, in sectors where innovations are made by laggard firms with already low initial profits, the negative Schumpeterian effect dominates.

Table 4.4 **Channels of deregulations' influence on number of patents applied by firms during sample period 1967-2004.** This table investigates through what channels deregulation influences the firm innovation behaviors. The OLS regression estimates for Eq.(8). The dependent variable is the natural logarithm of one plus the patent filed firms through sample period 1967-2004. Panel A reports the results of regression on the subsamples of all firms solely in the five deregulated industries. Panel B reports the results of regression on the subsamples of innovating firms in the five deregulated industries. Difference-in-differences estimations of the parameters of two-way fixed effects Ordinary Least Squares regressions are presented. Year fixed effects and industry fixed effects are included in all five regression, but the estimations are not presented. Both coefficient estimates and standard errors are reported. Significant at *** 1%, **5% and *10%.

Depdent Variables	Panel A: All dregulated firm		Panel B: All innovating deregulated firms	
	LnPCounts$_{i,t}$[a]		*LnPCounts*$_{i,t}$[a]	
	Coef.	*Std.Er.*	Coef.	*Std.Er.*
Deregtime	0.011**	0.214	-0.911***	0.432
ROA * Deregtime	-0.445 ***	0.370	-1.085***	0.628
Ln_age * Deregtime	0.142**	0.055	0.310***	0.108
Ln_mv * Deregtime	-0.09***	0.016	-0.134***	0.026
RDTA * Deregtime	-0.199***	3.866	-0.233***	5.304
PPETA * Deregtime	0.374*	0.162	0.543*	0.294
LEV * Deregtime	0.185	0.183	-0.156	0.321
CAPEXTA * Deregtime	-0.253	0.418	-0.119	0.705
Q * Deregtime	0.038	0.042	0.333	0.072
HINDEX * Deregtime	-0.691	0.515	0.534	0.785
$HINDEX^2$* Deregtime	1.182	0.679	0.165	1.022
ROA	0.396*	0.363	1.352**	0.601
Ln_age	-0.049	0.052	-0.276***	0.102
Ln_mv	0.254***	0.015	0.362***	0.024
RDTA	0.231***	0.385	0.287***	0.527
PPETA	-0.691***	0.150	-1.501***	0.268
LEV	-0.438**	0.174	-0.301	0.301
CAPEXTA	0.400	0.379	0.760	0.616
Q	-0.070*	0.041	-0.414***	0.069
HINDEX	0.150	0.454	-0.916	0.664
$HINDEX^2$	0.472	0.587	1.488	0.853
Intercept	-0.852***	0.209	0.772*	0.403
Year & industry FE	Included		Included	
No. of Obs. Used	8334		4477	
R2	0.201638		0.205679	

4.5 Industry-by-Industry Analysis

The results so far present average changes in firm innovation activities across all deregulated industries. A negative effect of deregulation on innovation activities is observed and the effect is not reverse-caused by a pre-existing trend in innovation output prior to deregulation. However, the results do not show whether the effect of deregulation on firm innovation activities is uniform or industry specific. Deregulation might influence firms in different industries in different ways. Aghion, Alesina and Trebbi (2007)'s analysis is that more democracy is followed by increased probability of entry. However, innovation incentives depend on the difference between the post-innovation and pre-innovation rents of incumbent firms. The competition encourages innovation by leading firms whereas it discourages innovation by laggard firms. The overall effect on aggregate innovation and growth depends upon the fraction of leading firms and laggard firms in the economy. On the other hand, regulation characteristics in different industries are different. For example, for some industries, regulatory practices may force firms to operate inefficiently. For this kind of industry, deregulation may raise firm profitability. For other groups of industries, regulatory practices protect firms from market competition and keep prices above marginal cost. In this case, deregulation might have an opposite effect on profitability in the way of pushing firms to a market with competitive market prices. Additionally, deregulation may influence firms' investment decisions in different ways. Capital intensity may actually stimulate innovation in industries subject to the "rate-of-return" regulation, such as utilities (Averch and Johnson, 1962). Other characteristics of regulation, however, may impede innovation.

In this section, I follow the matching firm procedure used by Ovtchinnikov (2010) to draw inferences about deregulated firms and employ the difference-in-difference approach to analyze changes in the innovation behavior of firms around deregulation for each industry.

I focus on firms in each of the five deregulated industries and select matching firms for each of them as a control group. Firms in treated group are all firms in each of the five deregulated industries. Firms in control group are selected from all non-deregulated firms. The matching firm selecting procedure follows four steps: First, I compute the average value of ROA, market value and Tobin's Q for all firms in each industry in the year prior to the year when the first deregulation initiative of that industry is adopted. I match these three variables because, according to the previous analysis, these three variables have significant effects on innovation activities. Second, all non-deregulated firms are sorted based on the value of ROA, market value and Tobin's Q and sorted to independent quartiles. After the sorting procedure, firms with the lowest value of the variable are placed in the first quartile and firms with the highest value of variable are placed in the last quartile. I sort firms based on three variables separately, thus I get 64 portfolios of firms according to their ROA, market value and Tobin's Q values. Third, I calculate the portfolio breakpoints in the year prior to the year when the first deregulation initiative of each industry is adopted and calculate the average value and value range of each variable for each quartile. Forth, for firms in each industry, I compare the average value of each of the three variables with the average value of each of the three variables of each quartile, and from the set of 64 non-deregulated firm portfolios, I select the portfolio of firms in the same ROA, market value and Tobin's Q quartile as the average deregulated firm in the year prior to deregulation as the control group for each industry. After the matching procedure, I get five subsamples. Each subsample consists of the observations of firms in one of the five deregulated industries and the observations of the matching control group of firms through the sample period 1967-2004. For each subsample I run the OLS regression as follows:

$$LnPCounts_{i,t+1}^{a} = \alpha + \beta_1 Deregind_{it} + \beta_2 (Deregtime_{it} \times Deregind_{it}) + \beta_3 X_{it} + \vartheta_t + \gamma_j + \varepsilon_{it} \quad (9)$$

The results are presented in Table 4.5 separately for each industry. β_2 is the difference-in-differences coefficient that I am interested in. The industry-in-industry results show that the trends I found from previous analysis are consistent across most of the deregulated industries, except for the petroleum and natural gas industry. For entertainment, utilities, communication and transportation, deregulation has a significant negative effect on firm innovation behavior. Following deregulation, firms in the petroleum and natural gas industry innovate 25% more than firms in matching non-deregulated industries. Firms in the entertainment industry innovate 13.29% fewer than firms in matching non-deregulated industries. Firms in the utilities industry innovate 25.4% fewer. Firms in the communicate industry innovate 62.75% fewer and firms in the transportation innovate 25.56% fewer. Figure 4.4 shows the average numbers of patents applied for by each of the five industries over the sample period, by application year. The petroleum and natural gas industry is more innovative than all the other four industries. Relatively, utilities and transportation are not innovative industries. Following Aghion et al. (2006), I assume that innovation is important as industry approaches the technology frontier; industries closer to their respective frontier are more innovation intensive. The numbers in Figure 4.4 imply that the petroleum and natural gas industry is closer to the technological frontier than the others. According to Aghion et al.(2006), deregulation on entry and price enhance the growth of innovation for industries close to the technological frontier. The results in Table 4.5 provide evidence for this theory. The petroleum and natural gas industry is different from other four industries in that it is relatively competitive (Viscusi, Harringron and Vernon, 2005), while entertainment, utilities, communication and transportation, are all industries that have technological leaders and laggards.

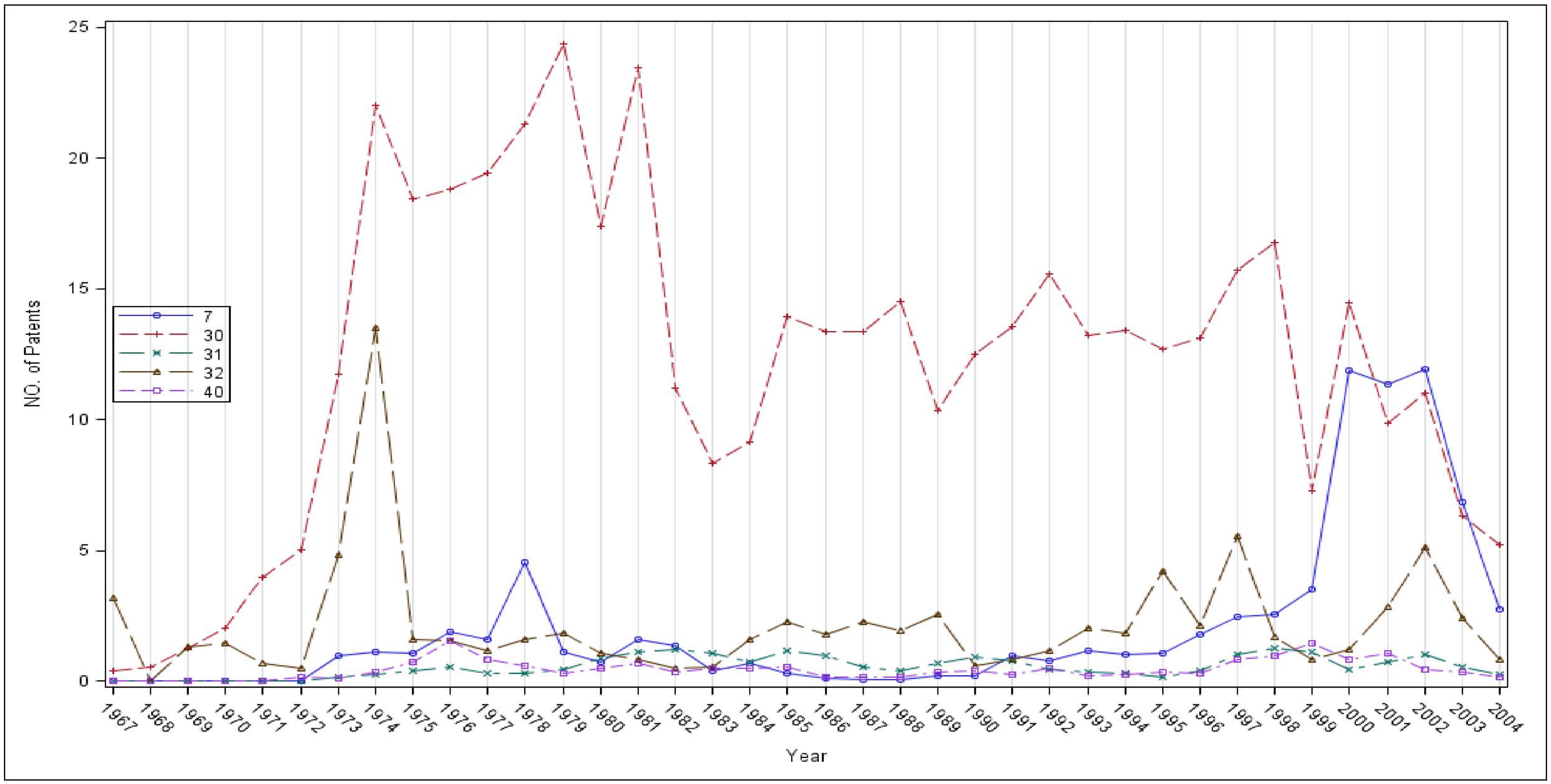

Figure **4.4 Average numbers of patents applied by each of the five industries over the sample period by application year, 1967-2004.** The five deregulated industries are: petroleum and natural gas (30) industry. For entertainment (7), utilities (31), communication (32) and transportations (40).

Table 4.5 **An industry-by-industry difference-in-difference estimation of the effects of deregulation on number of patents filed by firms in five deregulated industries through the sample period, 1967-2004.** This table investigates how deregulation affects the innovation behavior of firms in different industries. Each of the five subsamples used in this analysis consists of firms in each of the five deregulated industries and their matching firms. The dependent variable is the natural logarithm of one plus the patent filed firms through sample period 1967-2004. Difference-in-difference estimations of the parameters from two-way fixed effects Ordinary Least Squares regressions are presented. Year fixed effects and industry fixed effects are included in all five regressions, but the estimations are not presented. Both coefficient estimates and standard errors are reported. Significant at *** 1%, **5% and *10%.

Depdent Variables	*Pet &gas*		*Entertainment*		*Utility*		*Telecommunication*		*Tansportation*	
	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*	Coef.	*Std.Er.*
Deregind*Deregtime	0.174*	0.134	0.136	0.131	-0.174*	0.104	-0.627***	0.150	-0.219***	0.072
Deregind	0.254**	0.115	-0.612***	0.112	-1.769***	0.096	-0.183*	0.144	-0.245***	0.066
ROA	-0.559***	0.171	0.182	0.190	-0.957*	0.508	-0.234*	0.131	0.282**	0.141
Ln_age	0.182***	0.039	0.223***	0.052	0.013	0.051	0.253***	0.037	0.008	0.029
Ln_mv	0.324***	0.011	0.168***	0.018	0.108***	0.018	0.153***	0.011	0.102***	0.010
RDTA	0.391***	0.708	0.650***	0.933	0.277***	0.176	0.358***	0.433	0.404***	0.639
PPETA	-0.729***	0.136	-0.090	0.151	0.876***	0.150	0.242***	0.120	-0.183*	0.094
LEV	-0.519***	0.117	-0.243	0.142	-1.237***	0.173	0.216***	0.090	0.061	0.087
CAPEXTA	-0.105***	0.342	-0.524	0.509	0.179***	0.586	0.085	0.383	-0.470*	0.252
Q	-0.079***	0.020	-0.006	0.026	-0.179*	0.075	-0.003	0.015	-0.024	0.018
HINDEX	2.307***	0.447	-0.473	0.493	-1.200	0.443	0.432	0.395	0.047	0.279
HINDEX2	-1.417***	0.513	1.101*	0.655	1.292*	0.648	0.068	0.518	-0.085	0.359
Intercept	-2.081***	0.222	-0.712***	0.293	1.169	0.292	-0.930***	0.156	-0.076	0.140
Year & industry FE	Included		Included		Included		Included		Included	
No. of Obs. Used	3194		2150		2127		3070		2509	
R2	0.354952		0.39353		0.526397		0.36178		0.28688	

Chapter 5

CONCLUSION

The economic deregulation trend during the 1970s-1990s is recognized as one of the most significant experiments in modern economic policy, and it dramatically changed the operating environment of the industries and the competition environment of the firms and through these influenced the whole economy. The five industries, which experienced significant economic deregulation during the period of the 1970s-1990s, were all monopolies or oligopolies in nature. Following economic deregulation on price, entrance and exit, the production and service markets became more competitive for the particular industries analyzed here. More new firms and competitors entered the market. The industry structure became leveled with leaders and laggards. The market price of products became more competitive. The incumbent firms become more conscious about their unfavorable situation, and in order to stay profitable, one effective way was to adjust their innovation behavior and technology, acquiring behavior to protect them from the competition. The new entrants also needed to figure out their own innovation strategies to survive in the competitive environment. In this dissertation, about 40 years after the deregulation process began, I modeled the effect of the significant economic deregulation on firms' innovation behavior to find out whether the regulation reform really boosted the firm innovation activity or not, using the updated U.S firm level data.

Theoretically, deregulation effects firm innovation behavior in two ways: First, Schumpeter (1942) proposed that enhanced market competition negatively affects technological progress by reducing the monopoly profitability that rewards new innovation. Second, both price and entry deregulations change the terms of entry, an increase in entry threat that might encourage the incumbent firms innovate, which is called "escape-entry effect" by Aghion et al. (2009). Thus, the first way has a negative effect on firm innovation activity, while the second way, the "escape-entry effect", has a positive effect on firm innovation activity. The final effect of deregulation on aggregate innovation behavior depends on which of the two ways dominates and the relative strength of the two kinds of effects.

I analyzed innovation activities of firms in five deregulated industries: entertainment, petroleum and natural gas, utilities, telecommunications and transportation, compared to firms in other non-deregulated industries. My empirical research found that the increasing competition level of the production market following deregulation has a negative effect on the innovative behavior of firms in the five deregulated industries during sample period 1967-2004, which is consistent with the prediction of Aghion et al. (2005) and Schumpeterian models.

The baseline difference-in-differences models show that the economic deregulation has a negative impact on the number of patents filed by firms in the five deregulated industries, when compared with the number of patents filed by firms in non-deregulated industries. The economic deregulation also has negative effect on innovation quality of deregulated industries. The citation counts decline compared to non-deregulated industries following deregulation. The decline rate is even larger than the decline rate of patent counts, because the firms may adjust their R&D investment strategy to narrow their innovation technology field in order to control the risk and cost. Thus the decline of innovation quality is an appropriate indictor of the negative effect of deregulation.

Second, to find out how the deregulation cause such a decline in firm innovation activities, I took the difference-in-difference empirical model further and focused solely on firms in five deregulated industries and showed that deregulation alone has led to a 19.4% decline in patenting of deregulated firms. The effect of firm's profitability, which is an indicator of net competition effect, is responsible for a 4.5% decrease in innovation. The Schumpeterian effect dominates.

Third, I focused on firms in each of the five deregulated industries and selected matching firms for each of them as a control group, and then applied the difference-in-differences model on each of the five subsamples, and found that the deregulation positively affects the patenting behavior of firms in petroleum and natural gas industry. Deregulation has a negative effects on patenting behaviors of firms in the other four deregulated industries. This result is consistent with Aghion et al.(2006): deregulation on entry and price enhances growth of innovation for industries close to the technological frontier.

This dissertation contributes to both finance and economic literatures. First, it contributes to finance literature by examining the determinants of firm level innovation activities under economic deregulation environment. Second, it contributes to economics literature by examining the real effects of economic regulation reform by using firm level data. By developing a difference-in-difference empirical framework, I provide evidence that the real innovation activities inside of the five deregulated industries weren't increased by deregulation as much as expected, which enhances the current economic deregulation research literature. The economic deregulation is conducted in the five particular industries, the firms in these five industries adjusted innovation behaviors. However, all sectors in the economy are related to each other, a shock in one sector will lead to a multiplier effect in the whole economy. Thus further research can be done in the future to find out how the deregulation in the five particular industries will influence the innovation activities and operating environments of firms in related industries.

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Appendix

Appendix A

DISTRIBUTIONS OF LAG YEARS OF PATENT DATA

A.1 Distributions of Lag Years: Number of years from patent application year to grant year for patents granted between 1976 and 2006, assuming that the maximum number of lag years is nine.

	Grant Years Prior to Observations									Observed Grant Years																															Grant Years After Observations								
Application year	1967	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
1967	0	1	2	3	4	5	6	7	8	9																																							
1968		0	1	2	3	4	5	6	7	8	9																																						
1969			0	1	2	3	4	5	6	7	8	9																																					
1970				0	1	2	3	4	5	6	7	8	9																																				
1971					0	1	2	3	4	5	6	7	8	9																																			
1972						0	1	2	3	4	5	6	7	8	9																																		
1973							0	1	2	3	4	5	6	7	8	9																																	
1974								0	1	2	3	4	5	6	7	8	9																																
1975									0	1	2	3	4	5	6	7	8	9																															
1976										0	1	2	3	4	5	6	7	8	9																														
1977											0	1	2	3	4	5	6	7	8	9																													
1978												0	1	2	3	4	5	6	7	8	9																												
1979													0	1	2	3	4	5	6	7	8	9																											
1980														0	1	2	3	4	5	6	7	8	9																										
1981															0	1	2	3	4	5	6	7	8	9																									
1982																0	1	2	3	4	5	6	7	8	9																								
1983																	0	1	2	3	4	5	6	7	8	9																							
1984																		0	1	2	3	4	5	6	7	8	9																						
1985																			0	1	2	3	4	5	6	7	8	9																					
1986																				0	1	2	3	4	5	6	7	8	9																				
1987																					0	1	2	3	4	5	6	7	8	9																			
1988																						0	1	2	3	4	5	6	7	8	9																		
1989																							0	1	2	3	4	5	6	7	8	9																	
1990																								0	1	2	3	4	5	6	7	8	9																
1991																									0	1	2	3	4	5	6	7	8	9															
1992																										0	1	2	3	4	5	6	7	8	9														
1993																											0	1	2	3	4	5	6	7	8	9													
1994																												0	1	2	3	4	5	6	7	8	9												
1995																													0	1	2	3	4	5	6	7	8	9											
1996																														0	1	2	3	4	5	6	7	8	9										
1997																															0	1	2	3	4	5	6	7	8	9									
1998																																0	1	2	3	4	5	6	7	8	9								
1999																																	0	1	2	3	4	5	6	7	8	9							
2000																																		0	1	2	3	4	5	6	7	8	9						
2001																																			0	1	2	3	4	5	6	7	8	9					
2002																																				0	1	2	3	4	5	6	7	8	9				
2003																																					0	1	2	3	4	5	6	7	8	9			
2004																																						0	1	2	3	4	5	6	7	8	9		
2005																																							0	1	2	3	4	5	6	7	8	9	
2006																																								0	1	2	3	4	5	6	7	8	9

Table A.2 Unweighted number of patents in the sample from 1976 to 2006 in each application year-grant year combination

	Grant Years Prior to Observations									Observed Grant Years																															Grant Years After Observations									Total Number of Patents in Sample in Each Application	Total Number of Patents in Sample in Five Application	Distribution of Number of Unweighted Patents by 5-Year Groups – Lag Years									
Application year	1967	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15			9	8	7	6	5	4	3	2	1	0
1967										46	16	15	15	20	7	7	2	2	0	0	7	0	0	6	3	1	1	2	0	1	4	0	0	0	1	1	2	0	0	0										159											
1968										64	30	22	12	14	8	11	4	2	2	2	3	2	1	4	3	1	2	0	0	0	4	0	0	0	1	1	0	0	0	0										193											
1969										148	48	28	9	14	4	7	4	1	1	2	5	1	2	7	4	1	2	4	0	0	0	4	1	1	0	1	0	0	0	0										299											
1970										282	84	55	14	19	12	13	7	2	0	1	3	2	1	6	5	2	5	1	1	2	0	4	0	2	1	0	2	1	0	0										527											
1971										725	215	78	30	30	13	19	10	8	0	2	3	2	1	5	5	2	0	0	2	4	0	0	3	2	1	0	0	0	0	0										1,160	2,338	148	197	310	497	725					
1972										1344	482	144	52	52	19	18	9	7	5	7	5	1	1	3	7	0	2	3	0	2	0	1	2	1	0	2	0	1	0	0										2,170	80%	6%	8%	13%	21%	31%					
1973										6506	1108	444	123	79	31	22	10	12	7	5	1	1	2	9	15	3	1	3	2	4	0	1	1	1	1	1	0	0	1	0										8,394											
1974										32455	4328	1016	348	166	70	44	16	10	11	5	4	3	3	3	6	0	8	4	0	3	1	0	2	5	1	1	0	1	0	0										38,514											
1975										28018	30717	5248	800	508	187	71	34	20	9	2	8	3	1	6	5	6	2	2	2	1	1	3	1	4	0	7	0	1	1	0										65,668											
1976										1064	27887	31122	4185	1306	539	182	64	36	9	8	12	3	3	7	5	4	4	2	1	2	0	0	0	4	2	2	1	0	0	0										66,454	181,200	86	197	336	802	2,321	5,574	20,267	94,294	55,905	1,064
1977											842	27820	27540	8123	1417	540	213	74	37	14	11	6	12	6	12	0	4	6	2	1	2	0	0	2	3	1	8	4	2	0										66,702	100%	0%	0%	0%	0%	1%	3%	11%	52%	31%	1%
1978												705	16089	37441	9701	1402	486	236	98	50	24	18	12	6	6	1	7	0	3	1	0	0	0	2	5	0	1	1	0	0										66,295											
1979													97	14479	39620	9834	1262	624	312	113	63	21	13	14	10	9	5	2	6	5	1	1	0	0	1	0	0	1	0	0										66,493											
1980														60	14735	35485	13211	2309	760	356	214	48	40	19	11	15	8	7	2	3	3	2	3	0	5	2	1	1	0	0										67,300											
1981															106	10786	31977	17464	2757	708	517	253	107	48	35	14	8	12	8	9	4	3	0	2	7	1	3	0	1	3										64,833	331,623	147	305	752	1,634	3,118	9,147	58,333	172,063	83,909	1,810
1982																135	9938	33853	17088	2918	904	593	322	75	53	25	19	17	4	9	1	1	1	4	6	5	2	0	0	1										65,974	100%	0%	0%	0%	0%	1%	3%	18%	52%	25%	1%
1983																	324	12767	31646	12964	2834	916	602	209	61	31	20	14	17	13	6	4	2	4	3	2	2	0	2	1										62,444											
1984																		741	18979	31892	12507	2194	1110	470	125	46	35	18	25	20	8	1	5	5	6	1	0	1	0	1										68,190											
1985																			1026	22176	36949	8564	2432	1029	336	79	43	31	28	21	5	3	5	6	4	6	3	1	2	0										72,749											
1986																				717	28870	34121	9661	2004	800	199	61	49	18	18	6	6	2	7	5	2	3	2	1	1										76,553	345,910	168	274	796	2,200	4,759	12,382	60,784	168,461	92,730	2,943
1987																					1405	31207	40227	7215	1989	595	153	78	45	30	13	8	4	12	8	3	3	2	2	5										83,004	100%	0%	0%	0%	1%	1%	4%	18%	49%	27%	1%
1988																						1430	40054	37644	9505	2351	585	169	78	47	50	23	17	9	16	5	4	6	4	1										91,998											
1989																							2672	40623	40414	10824	2526	608	195	105	59	41	21	15	16	10	3	3	4	5										98,144											
1990																								2679	42509	41429	11168	2420	623	284	150	79	66	36	34	13	9	11	1	6										101,517											
1991																									2630	41066	42824	11743	2388	722	384	208	202	112	62	38	13	7	9	7										102,415	477,078	299	432	619	1,185	3,133	11,674	50,455	202,538	195,459	10,816
1992																										2771	40972	45709	11553	2475	975	666	494	314	180	68	42	19	7	9										106,254	100%	0%	0%	0%	0%	1%	2%	11%	42%	41%	2%
1993																											2053	40934	47325	13377	3202	1416	973	713	488	154	74	42	24	18										110,793											
1994																												2058	39451	55537	19042	5557	1765	1275	1012	408	183	90	41	30										126,449											
1995																													1881	38675	60766	31802	8255	3157	1903	1066	504	225	105	133										148,472											
1996																														1030	29617	73944	30126	8090	2987	1417	699	240	152	114										148,416	640,384.00	894	1,954	3,984	6,234	10,300	27,579	105,900	283,281	189,649	9,793
1997																															657	37033	80130	37874	11299	3728	1736	755	448	308										173,968	100%	0%	0%	1%	1%	2%	4%	17%	44%	30%	2%
1998																																525	33942	73115	41042	13802	5317	2212	1287	807										172,049											
1999																																	1592	36021	73913	38290	18573	8001	4038	2770										183,198											
2000																																		1033	35848	72816	41705	21449	12943	8710										194,504											
2001																																			1545	38270	70966	41158	24830	20198										196,967	920,686	308	1,255	4,812	16,696	50,187	89,953	200,069	370,940	181,114	5,352
2002																																				1704	32769	67818	39660	3205										174,008	100%	0%	0%	1%	2%	5%	10%	22%	40%	20%	1%
2003																																					1089	25973	48226	4735										122,644											
2004																																						789	15325	4785										63,967											
2005																																							611	1703										17,646											
2006																																								1069										1,069	379,334	-	-	-	-	-	32,057	87,016	163,897	91,102	5,262
Total Number of Patents in Sample in Each Grant Year (K)										71	66	67	49	62	66	59	58	68	73	72	84	79	97	92	99	99	101	104	104	112	115	151	158	162	170	172	174	169	148	178	3279									3,278,553	100%	0%	0%	0%	0%	0%	8%	23%	43%	24%	1%

Table A.3 Weighted number of patents in the sample from 1976 to 2006 in each application year-grant year combination

	Grant Years Prior to Observations									Observed Grant Years														
Application year	1967	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1967										634.6	220.7	206.9	206.9	275.9	96.57	96.57	27.59	27.59	0	0	96.57	0	0	82.77
1968										748.3	350.7	257.2	140.3	163.7	93.53	128.6	46.77	23.38	23.38	23.38	35.07	23.38	11.69	46.77
1969										1439	466.6	272.2	87.49	136.1	38.88	68.05	38.88	9.721	9.721	19.44	48.61	9.721	19.44	68.05
1970										2295	683.7	447.6	113.9	154.6	97.67	105.8	56.97	16.28	0	8.139	24.42	16.28	8.139	48.83
1971										4512	1338	485.4	186.7	186.7	80.9	118.2	62.23	49.79	0	12.45	18.67	12.45	6.223	31.12
1972										6679	2395	715.6	258.4	258.4	94.42	89.45	44.73	34.79	24.85	34.79	24.85	4.97	4.97	14.91
1973										22624	3853	1544	427.7	274.7	107.8	76.5	34.77	41.73	24.34	17.39	3.477	3.477	6.955	31.3
1974										73147	9754	2290	784.3	374.1	157.8	99.17	36.06	22.54	24.79	11.27	9.015	6.761	6.761	6.761
1975										48547	53223	9093	1386	880.2	324	123	58.91	34.65	15.59	3.465	13.86	5.198	1.733	10.4
1976										1813	47531	53044	7133	2226	918.7	310.2	109.1	61.36	15.34	13.64	20.45	5.113	5.113	11.93
1977											1503	49667	49167	14502	2530	964.1	380.3	132.1	66.06	24.99	19.64	10.71	21.42	10.71
1978												1400	31948	74347	19263	2784	965.1	468.6	194.6	99.29	47.66	35.74	23.83	11.91
1979													197.8	29521	80781	20051	2573	1272	636.1	230.4	128.5	42.82	26.51	28.54
1980														128	31440	75714	28188	4927	1622	759.6	456.6	102.4	85.35	40.54
1981															243.6	24788	73490	40136	6336	1627	1188	581.4	245.9	110.3
1982																313.6	23083	78630	39690	6778	2100	1377	747.9	174.2
1983																	714.5	28154	69786	28588	6250	2020	1328	460.9
1984																		1523	39009	65551	25707	4510	2281	966
1985																			1987	42937	71541	16582	4709	1992
1986																				1319	53103	62762	17770	3686
1987																					2487	55246	71214	12773
1988																						2481	69494	65312
1989																							4649	70680
1990																								4671
1991																								
1992																								
1993																								
1994																								
1995																								
1996																								
1997																								
1998																								
1999																								
2000																								
2001																								
2002																								
2003																								
2004																								
2005																								
2006																								
Total Number of Patents in Sample in Each Grant Year(K)										162	121	119	92	123	136	126	130	156	159	148	163	146	173	161

	Observed Grant Years																Grant Years After Observations								
Application year	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
1967	41.39	13.8	13.8	27.59	0	13.8	55.18	0	0	0	13.8	13.8	27.59	0	0	0									
1968	35.07	11.69	23.38	0	0	0	46.77	0	0	0	11.69	11.69	0	0	0	0									
1969	38.88	9.721	19.44	38.88	0	0	0	38.88	9.721	9.721	0	9.721	0	0	0	0									
1970	40.69	16.28	40.69	8.139	8.139	16.28	0	32.56	0	16.28	8.139	0	16.28	8.139	0	0									
1971	31.12	12.45	0	0	12.45	24.89	0	0	18.67	12.45	6.223	0	0	0	0	0									
1972	34.79	0	9.939	14.91	0	9.939	0	4.97	9.939	4.97	0	9.939	0	4.97	0	0									
1973	52.16	10.43	3.477	10.43	6.955	13.91	0	3.477	3.477	3.477	3.477	3.477	0	0	3.477	0									
1974	13.52	0	18.03	9.015	0	6.761	2.254	0	4.508	11.27	2.254	2.254	0	2.254	0	0									
1975	8.664	10.4	3.465	3.465	3.465	1.733	1.733	5.198	1.733	6.931	0	12.13	0	1.733	1.733	0									
1976	8.522	6.818	6.818	3.409	1.704	3.409	0	0	0	6.818	3.409	3.409	1.704	0	0	0									
1977	21.42	0	7.141	10.71	3.571	1.785	3.571	0	0	3.571	5.356	1.785	14.28	7.141	3.571	0									
1978	11.91	1.986	13.9	0	5.957	1.986	0	0	0	3.971	9.929	0	1.986	1.986	0	0									
1979	20.39	18.35	10.19	4.078	12.23	10.19	2.039	2.039	0	0	2.039	0	0	2.039	0	0									
1980	23.47	32.01	17.07	14.94	4.267	6.401	6.401	4.267	6.401	0	10.67	4.267	2.134	2.134	0	0									
1981	80.44	32.17	18.39	27.58	18.39	20.68	9.193	6.895	0	4.596	16.09	2.298	6.895	0	2.298	6.895									
1982	123.1	58.07	44.13	39.49	9.291	20.9	2.323	2.323	2.323	9.291	13.94	11.61	4.645	0	0	2.323									
1983	134.5	68.36	44.1	30.87	37.49	28.67	13.23	8.821	4.41	8.821	6.616	4.41	4.41	0	4.41	2.205									
1984	256.9	94.55	71.94	37	51.39	41.11	16.44	2.055	10.28	10.28	12.33	2.055	0	2.055	0	2.055									
1985	650.6	153	83.26	60.02	54.21	40.66	9.681	5.809	9.681	11.62	7.745	11.62	5.809	1.936	3.872	0									
1986	1472	366	112.2	90.13	33.11	33.11	11.04	11.04	3.679	12.88	9.197	3.679	5.518	3.679	1.839	1.839									
1987	3521	1053	270.9	138.1	79.66	53.11	23.01	14.16	7.081	21.24	14.16	5.311	5.311	3.541	3.541	8.852									
1988	16491	4079	1015	293.2	135.3	81.55	86.75	39.91	29.5	15.62	27.76	8.675	6.94	10.41	6.94	1.735									
1989	70316	18833	4395	1058	339.3	182.7	102.7	71.34	36.54	26.1	27.84	17.4	5.22	5.22	6.96	8.7									
1990	74110	72227	19470	4219	1086	495.1	261.5	137.7	115.1	62.76	59.28	22.66	15.69	19.18	1.743	10.46									
1991	4701	73401	76544	20989	4268	1291	686.4	371.8	361.1	200.2	110.8	67.92	23.24	12.51	16.09	12.51									
1992		5088	75229	83926	21212	4544	1790	1223	907	576.5	330.5	124.9	77.12	34.89	12.85	16.52									
1993			3957	78888	91205	25780	6171	2729	1875	1374	940.5	296.8	142.6	80.94	46.25	34.69									
1994				4230	81084	1E+05	39137	11421	3628	2621	2080	838.6	376.1	185	84.27	61.66									
1995					4205	86454	1E+05	71090	18453	7057	4254	2383	1127	503	234.7	297.3									
1996						2310	66437	2E+05	67579	18147	6700	3179	1568	538.4	341	255.7									
1997							1499	84469	2E+05	86387	25772	8503	3960	1722	1022	702.5									
1998								1263	81651	2E+05	98731	33202	12791	5321	3096	1941									
1999									3968	89779	2E+05	95434	46291	19942	10064	6904									
2000										2705	93879	2E+05	1E+05	56171	33895	22810									
2001											3953	97925	2E+05	1E+05	63535	51683									
2002												4069	78259	2E+05	94716	76559									
2003													2348	56011	1E+05	1E+05									
2004														1370	26601	83063									
2005															611	17035									
2006																1069									
Total Number of Patents in Sample in Each Grant Year(K)	172	176	181	194	204	236	252	339	361	385	421	437	438	409	338	365	7025								

	Total Number of Patents in Sample in Each Application	Total Number of Patents in Sample in Five Application	Distribution of Number of Weighted Patents by 5-Year Groups									
			Lag Years									
Application year			9	8	7	6	5	4	3	2	1	0
1967	2,193											
1968	2,256											
1969	2,907											
1970	4,289											
1971	7,219	18,865	1,558	1,849	2,608	3,633	4,512					
1972	10,784	75%	8%	10%	14%	19%	24%					
1973	29,189											
1974	86,803											
1975	113,783											
1976	113,264	353,823	257	586	923	2,152	6,522	16,434	48,605	179,415	96,077	1,813
1977	119,083	100%	0%	0%	0%	1%	2%	5%	14%	51%	27%	1%
1978	131,642											
1979	135,573											
1980	143,598											
1981	148,999	678,895	311.13	642.12	1595.16	3432.8	6450.1234	19149.66	122139.9	353499	167364.66	3472.5
1982	153,238	100%	0%	0%	0%	1%	1%	3%	18%	52%	25%	1%
1983	137,702											
1984	140,158											
1985	140,857											
1986	140,812	712,765	357	577	1,731	4,688	9,865	25,932	128,337	348,270	186,287	5,856
1987	146,942	100%	0%	0%	0%	1%	1%	4%	18%	49%	26%	1%
1988	159,617											
1989	170,761											
1990	176,985											
1991	183,057	837,361	526	763	1,089	2,085	5,503	20,482	88,556	355,613	342,931	18,989
1992	195,093	100%	0%	0%	0%	0%	1%	2%	11%	42%	41%	2%
1993	213,520											
1994	259,891											
1995	331,894											
1996	332,927	1,333,325	1,847	4,021	8,312	13,151	21,904	58,737	224,798	590,984	388,091	19,789
1997	396,804	100%	0%	0%	1%	1%	2%	4%	17%	44%	29%	1%
1998	413,881											
1999	456,603											
2000	509,367											
2001	503,999	2,280,654	703	2,963	11,722	42,155	126,813	224,971	495,084	915,153	447,702	13,388
2002	415,566	100%	0%	0%	1%	2%	6%	10%	22%	40%	20%	1%
2003	264,482											
2004	111,034											
2005	17,646											
2006	1,069	809,797	-	-	-	-	-	76,559	196,839	349,026	177,906	9,467
Total Number of Patents in Sample in Each Grant Year(K)	7,025,484	100%	0%	0%	0%	0%	0%	9%	24%	43%	22%	1%