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The Impact of the Act for the Development of Biotech and New Pharmaceuticals Industry on Firm Innovation in Taiwan

生技新藥產業發展條例對公司創新影響

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Abstract

This study investigates how the innovation activities of the biotech and new pharmaceuticals industry (biopharmaceutical industry) change after the exogenous shock of the enactment of the Act for the Development of Biotech and New Pharmaceuticals Industry (Biopharmaceutical Act). We adopt Propensity Score Matching (PSM) and Difference-in-difference (DID) approaches to deal with sample selection bias and endogeneity problems. We find that approved biopharmaceutical firms engage in more innovation investments after the passage of the Biopharmaceutical Act than unapproved firms. We also confirm the policy effectiveness of the Biopharmaceutical Act, finding that approved biopharmaceutical firms are more encouraged to engage in innovation activities than high-tech firms after the Biopharmaceutical Act. In addition, the stimulation effect on innovation exists only for pharmaceutical and low R&D intensity firms. In the subsample analysis of the inter-industry effects, the stimulation effect is driven primarily by low R&D intensity firms and small firms. These findings consolidate the effectiveness of the Biopharmaceutical Act for biopharmaceutical firms with more serious R&D underinvestment problems. Our investigation also shows the effectiveness of tax credits granted by the Biopharmaceutical Act for the R&D investment of biopharmaceutical firms in Taiwan.

【Keywords】innovation, R&D, tax credits, propensity score matching, difference-in-difference

摘 要

本研究探討生技新藥業發展條例（簡稱生技條例）對生技新藥業（簡稱生技業）研發創新的影響。我們採用「傾向分數配對法」與「差異中之差異法」來處理樣本選擇誤差與內生性問題。研究發現，在生技條例施行後，經生技條例核可的公司比未經核可的公司有較多的研發創新。我們也發現在生技條例施行後，經條例核可的公司會比高科技公司有較多的研發創新。再者，經生技條例核可的公司中，新藥公司與研發強度低的公司會致力於較多的研發創新。與高科技公司比較時，生技條例核可的公司中，研發強度較低的公司與小公司會有較多的研發創新。這些發現隱含條例對於研發較嚴重投資不足的公司的激勵效果較強。我們的研究亦驗證政府對於生技業所提供的課稅減免優惠對刺激該產業投資研發創新有正向的鼓勵作用。

【關鍵字】研發創新、課稅抵減、傾向分數配對法、差異中之差異法、生技新藥業發展條例

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1. Introduction

Government policies are commonly used to encourage firms to increase their investments in Research and Development (R&D). In general, R&D investments and innovation activities are key sources of growth and sustained operations of a firm and/or a nation (Romer, 1990; Aghion and Howitt, 1992). However, the nature of R&D activities, which includes high uncertainty, long-run cumulative effect, imperfect appropriability, and high information asymmetry between investors and managers, causes R&D investment to fall below the socially optimal level (Aghion, Van Reenen, and Zingales, 2013; Arrow, 1962; Brown, Martinsson, and Petersen, 2012; Bushee, 1998; Jones and Williams, 1998; Porter, 1992). To solve the R&D underinvestment problems, many countries adopt public policies such as tax credits and direct subsidies to stimulate R&D because these policies can ameliorate funding issues and indirectly eliminate the financing difficulty problem of R&D (Aerts and Schmidt, 2008; Czarnitzki and Hussinger, 2004; Cerulli and Potì, 2012; Czarnitzki, Hanel, and Rosa, 2011; Yang, Huang, and Hou, 2012; Hall and Van Reenen, 2000).

In Taiwan, the problem of R&D underinvestment in the biotech and new pharmaceuticals industry (biopharmaceutical industry) is particularly severe. The biopharmaceutical industry and high-tech industry are respectively the first and second highest R&D intensity industries in Taiwan for the period 2007-2017.[1] Brown, Martinsson, and Petersen (2017) argue that the industries with more R&D intensity are more likely to experience innovation underinvestment. In 1982, the Science and Technology Development Plan of Taiwan listed these two industries as important development items for the nation. After decades of struggles, Taiwan's economy is mainly supported by the high-tech industries, including electronic components, information services, semiconductors, and optoelectronics technology.

However, the growth of the biopharmaceutical industry is relatively limited and

1 The biopharmaceutical industry includes pharmaceutical, biomedical material, and health care firms. The high-tech industry consists of computers and peripherals, semiconductors, consumer electronics retailing, optoelectronics, telecommunication and networking, electronic components, information technology services, and other electronics. Our untabluated results show that R&D intensities, the ratio of R&D expenditure to total assets, for the Biopharmaceutical and high-tech industries are 4.08% and 3.04%, respectively.

slow due to several reasons.[2] First, most Taiwan biopharmaceutical firms cannot obtain substantial funding to engage in R&D activities because their firm sizes are relatively small. Second, Taiwan's venture capitalists have less incentive to invest in domestic biopharmaceutical firms than in foreign ones because of less successful domestic cases in developing both new medicines and high risk medical devices.[3] Third, owing to the restrictions of new drug prices under the national health insurance policy, the relatively low ratio of health expenditure to GDP, and the domestic market-oriented patent authorization and technology, biopharmaceutical firms in Taiwan tend to have less incentive to engage in high risk innovation activities.[4] To address the R&D underinvestment problem and to provide a more favorable environment to the development of the industry, the Taiwan government adopts several public policies.[5]

Among these public polices, the Biotech and New Pharmaceuticals Development Act（生技新藥產業發展條例）, which was promulgated in 2007, is intended to promote innovation investment in the biopharmaceutical industry.[6] The Biopharmaceutical Act primarily uses tax credits to spur R&D. Theoretically, the effectiveness of tax credits appears to be stronger in encouraging R&D than direct subsidies for several reasons. First,

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2 The reasons are summarized from reports of Biopharmaceutical Industry White Paper of Industrial Development Bureau, Ministry of Economic Affairs.

3 According to Taiwan Venture Capital Association (2008)（2008 年臺灣創業投資年鑑）, capital invested in biopharmaceutical industry accounts for less than 10% of annual venture capital from 2001 to 2007. By contrast, capital invested in high-tech industry accounts for more than 25% of annual venture capital in the corresponding time period.

4 According to the "Development of the biotechnology and pharmaceutical industry in Taiwan (The report on the monthly meeting of the presidential palace)" of Wong (2007)（政策焦點：生技製藥產業在台灣的發展（2007 年 7 月總統府月會專題報告））the ratio of health expenditure to GDP in Taiwan, which is about 5.3-5.4%, is lower than the average 7.8%, of developed countries. In addition, Chen (2017) finds that the restrictions on new drug prices under the national health insurance policy tend to discourage companies from developing and selling new drugs in Taiwan. Further, Sun (2003) argues that the main sources for companies to obtain patent authorization and technology introduction are domestic, which shows that the development of Taiwan's biotechnology industry is limited to the domestic market and local technology status.

5 These policies include "Action Plan for Strengthening the Biotechnology Industry"（加強生物技術產業推動方案）in 1995, "Relaxing the Listing for Biopharmaceutical Industry"（放寬生技公司上市（櫃）標準）in 2001, and "Act for the Development of Biotech and New Pharmaceuticals Industry" (Biopharmaceutical Act)（生技新藥產業發展條例）in 2007.

6 We focus on the Biopharmaceutical Act of 2007 rather than other related public policies or regulations of the Biopharmaceutical industry because data on listed firms from 1995 to 2001 are not available.

previous studies argue that the government may not grant subsidies to proper projects or firms with high social return (e.g., Wallsten, 2000; Winston, 2006) because of government failure resulting from political pressure, corruption, and bureaucratic objectives. By contrast, tax credits decrease the marginal cost of R&D. Thus, the incentive function of tax credits is determined by the benefit and cost analysis of R&D rather than government failure. Second, the recipients of subsidies may not devote efforts to R&D after receiving the funds from government. Tax credits generally do not have this moral hazard problem because the firms must increase R&D investment to obtain the credits. Accordingly, the tax credits used in Biopharmaceutical Act should be more effective for R&D than direct subsidies.

In addition to tax credits, the Biopharmaceutical Act also adopts non-tax credit tools. First, the Biopharmaceutical Act grants managers and employees the firms' shares and share warrants to increase managers' motivation to invest in R&D. Second, the Act relaxes certain restrictions on employees to increase collaboration between industries and academic institutions, which allows the biopharmaceutical firms to obtain the knowledge of R&D incoming spillover from other institutions. Therefore, these non-tax credit tools could also alleviate the R&D underinvestment problems.

Although previous studies have investigated the effects of Biopharmaceutical Act on innovation (Chen, 2013; Hsu, 2018; Kao, 2012), they do not have consistent results. By comparing the data before and after 2007, Chen (2013) finds significant decreases in R&D expenditure after the Biopharmaceutical Act. Kao (2012) adopts the direct subsidy of R&D from the government, the amount of tax credit from the Biopharmaceutical Act, and the amount of government direct investment as policy proxies for the influence of the Biopharmaceutical Act, and finds no significant impact of these policies on biotechnology patents. Moreover, Chen (2013) and Kao (2012) both examine the change in innovation for the biopharmaceutical industry before and after the Biopharmaceutical Act, but they may suffer from endogeneity issues. Specifically, the difference between the pre- and post-Biopharmaceutical Act outcome may result from other exogenous influences such as the global financial crisis of 2007-2008. Hsu (2018) shows that the R&D expenditures of biopharmaceutical industry significantly increase after the Biopharmaceutical Act. Hsu (2018) also finds that firms which are approved under Biopharmaceutical Act (approved biopharmaceutical firms) tend to have higher R&D expenditures than those not approved (unapproved biopharmaceutical firms). Hsu's (2018) findings thus support the positive influence of Biopharmaceutical Act on innovation. However, Hsu (2018) may also suffer

from endogeneity problems because the result may be driven by omitted variables. Accordingly, the abovementioned studies may not identify the actual effect of the Biopharmaceutical Act because these papers do not address the potential endogeneity.

To prevent the endogenous problem, we adopt Difference-in-difference (DID) approach to investigate. Namely, relative to control firms (i.e. firms could not obtain the benefits of the Biopharmaceutical Act), how treated firms (i.e. approved biopharmaceutical firms) respond to the exogenous shock of the Biopharmaceutical Act.[7] Before the DID approach, we use the Propensity Score Matching (PSM) method to identify comparable control firms which have characteristics similar to those of approved biopharmaceutical firms. For the control firms, we first consider biopharmaceutical firms which are not approved by the Biopharmaceutical Act. The intra-industry comparison between approved and unapproved firms enables us to identify the change in innovation from obtaining benefit from the Biopharmaceutical Act. Further, industries with higher R&D intensity are more likely to experience the innovation underinvestment problem (Brown et al., 2017). Yang et al. (2012) find that tax credits are more effective for R&D in industries with higher R&D intensity and suggest that the government should establish tax credits across industries. As a result, we use the high-tech industry as a comparable control group since high-tech firms also have great R&D underinvestment problems; however, they cannot benefit from the Biopharmaceutical Act. This inter-industry comparison helps to evaluate whether the Biopharmaceutical Act is effective only for biopharmaceutical firms.

We collect firms approved under the Biopharmaceutical Act from the "2018 Biotechnology Industry White Paper of Bureau of Industry", Ministry of Economic Affairs (2018)（2018 生技產業白皮書）. From 2007 to 2018, there are 134 approved biopharmaceutical firms, with 65 of these being listed firms. Accounting information is collected from the Taiwan Economic Journal (TEJ) database. We use R&D intensity (the ratio of R&D expenditure to total assets) as the proxy of R&D investments and adopt patent adjusted citation as the proxy of innovation quality. The patent data are collected from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT), from which we choose patents applied with the United States Patent and Trademark Office

7 The control firms are matched firms for the approved biopharmaceutical firms. Because the approved biopharmaceutical firms receive the Biopharmaceutical Act benefits, the control firms are the ones which do not obtain the benefits from the Act.

(USPTO), since we only focus on U.S. patents applied by Taiwanese firms.[8]

Our empirical results show that innovation activities are encouraged by the Biopharmaceutical Act. First, unlike unapproved firms, approved biopharmaceutical firms significantly increase their R&D investments after the Biopharmaceutical Act. However, these firms have not significantly improved innovation quality yet. In addition, the encouragement effect in the intra-industry analysis only occurs for pharmaceutical and low R&D intensity firms. Second, the approved biopharmaceutical firms exhibit significantly more innovation activities and higher innovation quality than high-tech firms after the Biopharmaceutical Act. This result of the inter-industry comparison over innovation investment primarily exists in low R&D intensity firms and small firms while the result of inter-industry comparison over innovation quality only exists among large firms. Therefore, our findings support the policy effect of the Biopharmaceutical Act on innovation.

Our paper contributes to the literature regarding the effect of the Biopharmaceutical Act on innovation in several ways. First, we conduct DID approach to avoid the endogeneity problem, which previous studies did not particularly address (Chen, 2013; Hsu, 2018; Kao, 2012). This makes our results more reliable and also reduces the influences of other exogenous shocks and other potential factors. Second, we find that the approved biopharmaceutical firms (beneficiaries of the Act) have greater investments in innovation than unapproved biopharmaceutical firms and high-tech firms (non-beneficiaries of the Act) have after the Biopharmaceutical Act. Our results confirm with previous studies that tax credit policy can encourage innovation activity. In addition, our finding from the inter-analysis supports the argument of Yang et al. (2012) that government should establish tax credits across industries. This finding also confirms the policy effectiveness of the Biopharmaceutical Act, which grants tax credits only for biopharmaceutical firms. Third, we examine what types of firms derive greater benefits from the tax credit provisions of the Biopharmaceutical Act. We find that pharmaceutical firms and low R&D intensity biopharmaceutical firms exhibit greater innovation investments than unapproved biopharmaceutical firms after the Biopharmaceutical Act. We also find that small and low R&D intensity approved biopharmaceutical firms have higher innovation investments than

8 There are fewer citations received by the patents that are applied with and granted by the Taiwan Intellectual Property Office (TIPO). Thus, using TIPO patents could be more difficult to gauge patent citations. In addition, USPTO patents are usually regarded as more valuable (Huang and Chang, 2020).

high-tech firms after Biopharmaceutical Act. These findings imply that firms with more serious R&D underinvestment problems are more strongly encouraged to invest in R&D by the Biopharmaceutical Act.

The remainder of this paper is organized as follows. Section 2 reviews prior literature including studies on the R&D underinvestment problem, theoretical papers on public policies that encourage R&D investment, and important related public policies of other countries. Section 3 describes the data, defines the variables, and introduces the PSM and DID methodology. Section 4 shows the results of the intra-industry and inter-industry analyses, and the subsample analysis. Section 5 summarizes our findings and makes the conclusion.

2. Literature Review

The first part of this section discusses the nature of private R&D and the corresponding theoretical concepts that explain the R&D underinvestment problem. To address the R&D underinvestment problem, the government often adopts policies such as tax credits, direct subsidies, construction of national laboratories, and encouraging the cooperation between industry and academia. Among these public polices, the two primary policies used by the government to encourage private R&D are direct subsidies and tax credits. Therefore, we respectively use two subsections to illustrate and compare these two policies. Finally, to understand the effectiveness of the Biopharmaceutical Act in Taiwan, we consider the influence of tax credits and non-tax credits on R&D.

2.1 Theories that Explain the Underinvestment in Private R&D

Many papers argue that the nature of private R&D activities leads to underinvestment in R&D. First, the agency theory posits that the conflict of interest between managers and shareholders gives managers less incentive to engage in R&D. Managers usually have less incentive to innovate because the innovation process is long, unpredictable, heterogeneous, complicated, and has a high probability of failure. Porter (1992) and Bushee (1998) argue that myopic managers, who focus on profits to meet short-term goals, may cut R&D expenditures because R&D activities are usually long-term. In addition, Aghion et al. (2013) propose that risk-averse managers have less incentive to do R&D because these managers may be fired merely for having bad luck with risky investments. Further, lazy managers like to have a quiet and happy life and may not want to engage in R&D because

of the complications and long-term effort required (Aghion et al., 2013). Overall, the R&D underinvestment problem is derived from the agency problem of managers. Previous studies (Aghion et al., 2013; Bushee, 1998; Chang, Liang, and Wang, 2019) propose that institutional investors could alleviate the agency problem and thus ameliorate the problem of R&D underinvestment.

Second, spillover theory proposes that a firm cannot appropriate all the returns from its R&D investments and accordingly has less incentive to invest in R&D at the socially optimal level. Arrow (1962) and Jones and Williams (1998) suggest that firms may underinvest in innovation because it is difficult to conceal all knowledge of innovation from competitors. The free rider problem (or the imperfect appropriability) of R&D allows competitors to take advantage of firms' knowledge of R&D to reduce production costs or to increase profitability. Chen, Chen, Liang, and Wang (2013) further examine the outgoing spillover effect of R&D and discover that firms which are less able to appropriate their R&D benefits are more likely to underinvest in R&D. The protection of patent and intellectual property may help to eliminate the free rider problem of R&D investments. However, such protection is incomplete in the real world because of patent and intellectual property litigation (Bessen, Neuhäusler, Turner, and Williams, 2014).

Third, the financial constraint theory argues that relative to other investments, the R&D investment is more affected by financial constraints because of its greater uncertainty and its higher information asymmetry. Li (2011) argues that when a firm cannot raise enough funds to conduct the required tests of R&D, it may suspend the R&D project. Thus, R&D intensive firms with financial constraints are more likely to cut R&D investments. Brown et al. (2012, 2017) and Hsu, Tian, and Xu (2014) further investigate the external financing for R&D investments because R&D intensive firms often easily exhaust internal financing due to their lack of tangible assets and highly asymmetric information. They argue that equity markets are more suitable for the innovative firms to finance their R&D investments because equity markets provide investors with upside returns without collateral requirements and allow feedback of valuable information about the prospects of innovative projects. By contrast, Hall (2002) states that debt finance is less suited for R&D investment because of the limited collateral value of intangible assets and the high probability of failure in R&D. Accordingly, the improvement of equity financing for R&D investments (i.e. reducing the financing constraints on R&D investments) helps to reduce the R&D underinvestment problems of innovative firms.

2.2 The Effect of Government R&D Subsidies on Innovation

In order to promote R&D for economic growth, the government should grant subsidies to projects with high expected social benefit but with low returns for the private sector. There are two competing theories that explain the relationship between private R&D and public expenditures such as R&D subsidies: the substitution and complementary theories.[9] Theoretically, public subsidies can positively contribute to the private sector because the recipients of subsidies directly receive the profits of funds while non-recipients of subsidies indirectly obtain knowledge from R&D spillovers (David, Hall, and Toole, 2000; Özçelik and Taymaz, 2008; Chen, Chen, Liang, and Wang, 2020). Klette and Møen (2012) use the dynamic and long-run model and argue that government R&D subsidies produce positive learning-by-doing effects on private R&D. Takalo and Tanayama (2010) also use a theoretical model and suggest that government R&D subsidies directly reduce the financing constraints and can decrease the capital costs of innovative firms because the firms receiving the R&D subsidies provide informative signals to the market. Accordingly, these theoretical papers suggest that the complementary theory under which the subsidies produce additional effects for private R&D investments is the correct explanation.

Although above theoretical papers support the complementary theory, empirical studies show conflicting results (David et al., 2000; Wallsten, 2000; Wu, 2005). To assure the effectiveness of government subsidies, the government should choose target projects with high social returns that private firms would not undertake on their own. However, Wallsten (2000) finds that firms which devote more R&D tend to be more easily to receive government subsidies. Further, Wallsten (2000) does not find positive influence of subsidies on innovation because he finds that federal R&D grants decrease firm-financed R&D.[10] Wu (2005) and Toivanen and Niininen (2000) also find that the government direct subsidies crowd out firm R&D investments, meaning that direct subsidies substitute for private R&D expenditures. Becker (2015) argues that this crowding-out effect may result from the problem of sample selection bias. In fact, the government may favor certain

9 Substitution theory suggests that these two mechanisms replace each other: private R&D is reduced when the government infuses funds into the private sector. Complementary theory suggests that the public fund infusion of government policy ameliorates underinvestment in private R&D.

10 Wallsten (2000) posits several reasons that the government funds may provide firms with the ability to attract private funds and may allow the firms to delay refinance.

projects and firms with more promising outcomes (David et al., 2000; Klette, Møen, and Griliches, 2000; Lach, 2002). Such premeditated selection by the government appears to violate the assumption of the effectiveness of government subsidies. Thus, since these papers do not consider the endogeneity of the sample selection, their results may be biased.

By adopting new econometric techniques to control for selection bias, more recent studies are shifting away from the crowding-out effect of subsidies on private R&D to their stimulating effect on private R&D (Becker, 2015). Using a matching methodology for the samples, Czarnitzki and Hussinger (2004), Duguet (2004), and Carboni (2011) find that government subsidies have a positive effect on private R&D in German, French, and Italian firms, respectively. In addition, Aerts and Schmidt (2008) use a conditional DID estimator and also reject the crowding-out effect on private R&D in Flanders and Germany. Further, adopting a treatment analysis, Özçelik and Taymaz (2008) also support the additionality effect of government subsidies on private R&D in Turkish manufacturing firms. For Italian firms, Cerulli and Potì (2012) adopt matching methods and the DID estimator and also obtain a similar positive effect. Therefore, after controlling for the endogeneity problem, most empirical papers find that government subsidies did stimulate private R&D investments.

2.3 The Effect of Government Tax Credits on Innovation

The policy on R&D tax credits is a more market-oriented method, since it permits firms to decide the amount and timing of investing in R&D activities. In theory, David et al. (2000) and Czarnitzki et al. (2011) use the relationship between marginal return of R&D and marginal cost of R&D to explain firms' decisions to engage in private R&D. Both studies find tax credits decrease the marginal cost of R&D and thus result in higher private R&D investments. Namely, tax credits do not have crowding-out effects on private R&D because the tax credits shift the marginal cost curve downwards. Tax credits may thus result in two possible situations. First, tax credits may cause some firms that would not invest in R&D to engage in R&D investments instead when the marginal cost of R&D in these firms is greater than the marginal return of R&D. Second, the recipients of tax credits may be induced to infuse more investment projects with less profit. Under this micro-level framework, tax credits decrease the marginal cost of R&D. Thus, these two papers support the financial constraint hypothesis under which the tax credit ameliorates the financial constraint problem and increases R&D investments.

The empirical studies find that tax credits have a positive effect on R&D investment, though the results of estimators vary depending on the sample data, model specification, and methodology. Without the tax credits for R&D, the expense labelled or not labelled as the R&D investment is indifferent for a firm. However, when the government provides preferential tax treatment for R&D investments, firms generally prefer to label expenses as R&D investments. Considering the relabeling problem of R&D, which may cause overestimation of the effect of R&D, Hall and Van Reenen (2000), using the data of OECD countries, still find that each dollar of tax credits for R&D increases R&D investments by a dollar.

In addition, assessing the effect of R&D tax credits suffers from the selection bias problem because the recipients of tax credits may have characteristics different from those of non-recipients. Czarnitzki et al. (2011) adopt the non-parametric matching method to remove the selection bias problem and support the effectiveness of tax credits on innovation output for Canadian firms. Yang et al. (2012) investigate the tax credit policy of Taiwan and use the PSM approach to eliminate selection bias problems. By adopting detailed information about the amount of R&D tax deduction as the instrumental variable and a generalized method of moment methodology to control for endogeneity and firm heteroskedasticity, Yang et al. (2012) also find that tax credits stimulate additional R&D investments.

2.4 Direct Subsidies versus Tax Credits

In terms of the effects on the private R&D decisions, direct subsidies are different from tax credits. In practice, target firms or projects may not be randomly granted subsidies. Winston (2006) proposes that political pressure, corruption, and bureaucratic objectives may result in government's failure to select proper firms or projects. In addition, direct subsidies may cause moral hazard problems because the recipients of subsidies may not devote their efforts to R&D activities after obtaining funds from the government. By contrast, tax credits do not engender moral hazard problems because firms must increase R&D investments to obtain the credits. Further, firms would recalculate benefits and costs to decide their investments in R&D while tax credits reduce the cost of R&D. The credit granted depends on the market-oriented R&D decision of firms rather than the government's discretionary decision. Accordingly, the problems of government failure and moral hazard from the direct subsidies imply that tax credits are more effective in encouraging R&D.

The time patterns of the stimulus effects of tax credits and direct subsidies are also

different. David et al. (2000) find that the recipients of tax credits tend to use additional funds from tax credits to preferentially invest in projects with the highest private return because tax credits reduce the marginal cost of R&D. Based on this concept, David et al. (2000) suggest that the stimulating effect of tax incentives is strong in the short-run because the recipients of tax credits tend to concentrate in the projects with short-term prospects. By contrast, firms or projects granted subsidies by government are selected because they can benefit the general social welfare but the firms themselves may not receive benefits. In theory, projects with high expected social benefits but with insufficient private expected returns usually have long-term nature. Therefore, the stimulus effect of tax credits on innovation is generally faster than that of direct subsidies.

2.5 The Effect of the Taiwan Biopharmaceutical Act on R&D

In Taiwan, the Biopharmaceutical Act is established to promote R&D investment of biopharmaceutical industry. The Biopharmaceutical Act adopts two main policy tools to stimulate R&D: tax credits and non-tax credits. First, Biopharmaceutical Act provides tax credits on profits if the expenditure of R&D and personnel training of a particular year exceeds the average of the expenditure of the previous two years. This regulation decreases the cost of R&D investment, which is consistent with the theoretical concept of tax credit (David et al., 2000; Czarnitzki et al., 2011). The Act also offers tax credits for holding shares of biopharmaceutical firms and grants tax credits to top executives and technology investors for their new shares in biopharmaceutical firms. Such a regulation can increase equity financing opportunities and is therefore consistent with the argument of previous papers (Brown et al., 2012, 2017; Hsu et al., 2014) that the equity market is more suited to financing R&D investments. Therefore, the decreasing cost of R&D investment and the incentive of equity financing tend to support the financial constraint theory in explaining R&D underinvestment.

Based on the comparison of literature between the two policies, if the government wants to more strongly promote R&D, it should adopt tax credits rather than direct subsidies. In fact, the Biopharmaceutical Act primarily uses tax credits. Thus, we infer that the government's policy is good. In addition, we predict that the effectiveness of Biopharmaceutical Act is stronger in the short run than in the long run because the stimulating effect of tax credits is more rapid than that of direct subsidies (David et al., 2000).

Second, the biopharmaceutical industry also provides non-tax credit treatment as

follows. The Biopharmaceutical Act grants the managers and employees of the firms a share and share warrant. This regulation reduces the agency problems between managers and shareholders and thus increases the managers' incentive to invest in R&D. In addition, the Biopharmaceutical Act also relaxes restrictions on employees to increase the collaboration between firms and academic institutions. This can increase the effectiveness of R&D spillover from other institutions to biopharmaceutical firms. Therefore, the improvement effects encouraged by these non-tax credit treatments such as spurring managers' motivation and increasing cooperation opportunities tends to support the agency theory and spillover theory in explaining R&D underinvestment.

3. Data and Methodology

3.1 Data

The study investigates the influence of the Biopharmaceutical Act on firm's innovation for biopharmaceutical industry and high-tech industry. The biopharmaceutical industry and the high-tech industry are classified based on the definitions from the Taiwan Stock Exchange.[11] We collect firms which are approved under the Biopharmaceutical Act from the 2018 Biopharmaceutical Industry White Paper of Bureau of Industry, Ministry of Economic Affairs.[12] From 2007 to May 2018, 134 biopharmaceutical firms are approved by the Biopharmaceutical Act, 65 of which are listed firms.[13] There are 85 firm-year observations from the listed approved firms. From 2007 to 2017, 148 biopharmaceutical firms were not approved by the Biopharmaceutical Act. In addition, there are 11309 firm-year observations of the high-tech industry. We obtain the accounting information from

11 The definitions of the biopharmaceutical industry and high-tech industry are presented in Section 1.

12 If companies seek to be approved as biopharmaceutical companies, they should meet the requirements of the Biopharmaceutical Act. These regulations include "Regulation of Shareholder Investment Deduction for Biotech and New Pharmaceuticals Industry"（營利事業適用生技新藥公司股東投資抵減辦法）and "Regulation of Investment Deduction for Research and Development and Personnel Training Expenditures of Biotech and New Pharmaceuticals Industry"（生技新藥公司研究與發展及人才培訓支出適用投資抵減辦法）. Of these regulations, the most important requirement is that companies whose R&D expenses should have a significant proportion of their total operating income or paid-in capital.

13 The approved firms include firms listed in the stock exchange market, over-the-counter market, and emerging stock market, and also include unlisted companies.

the Taiwan Economic Journal (TEJ) database. We collect U.S. patent data of these target firms from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT) because it is more detailed and comprehensive and because it is widely used in the literature (Bena and Li, 2014; Chang et al., 2019; Chen et al., 2020; Li, Lai, D'amour, Doolin, Sun, Torvik, Yu, and Fleming, 2014).

3.2 Variables

3.2.1 Innovation Measures

We use R&D intensity as the proxy for R&D investments (innovation investments) and patent adjusted citation as the proxy for innovation quality. R&D expenditure is the innovation input while patents are the innovation output. Since the Biopharmaceutical Act of 2007 specifies the investment tax credit for R&D expenditures, this Act appears to encourage the approved biopharmaceutical firms to engage in innovation input. Several studies examine the sensitivity of R&D expenditure to R&D tax credit (Eisner, Albert, and Sullivan, 1984; Mansfield, 1986; Tillinger, 1991; Hall, 1993). Innovation activities require capital infusions and R&D expenditures. R&D expenditures are related to firm size: large firms can spend more on innovation. Firm size usually does not change substantially over time. Therefore, we first adopt R&D intensity, namely the ratio of R&D expenditure to total assets, as the quantitative measure of R&D investment (i.e. innovation input).[14]

Second, we adopt the patent adjusted citation as the innovation quality measure.[15] The patent citation is the total number of citations received from all successful patents that are filed by a firm. Patent citations have been widely used to measure the innovation output (Griliches, 1990; Hsu, 2009; Hsu et al., 2014; Trajtenberg, 1990).[16] However, patent citations suffer from the inevitable truncation problem, under which later patents receive

14 We adopt R&D/total assets as the measure of R&D intensity because it is the measure mostly used in the finance literature (Brown et al., 2017; Chen et al., 2013; Franzen, Rodgers, and Simin, 2007). We do not use R&D/sales because the amount of sales tends to fluctuate more than total assets over time, leading to unstable results.

15 Cohen, Nelson, and Walsh (2000) propose that patents are more valuable for appropriating R&D returns in high R&D intensity firms such as pharmaceutical and medical instrument firms than in low R&D intensity firms. Thus, we adopt patents as the innovation measure for biopharmaceutical firms.

16 In the early studies, patent count, which is the number of patents applied by a firm, is often used to measure the quantity of innovation (Griliches, 1981). However, recently, most studies use patent citations to measure the quality of innovation.

fewer citations because of their shorter time in existence. To prevent this problem, we follow Hall, Jaffe, and Trajtenberg (2001, 2005) to measure the patent adjusted citation by correcting the number of citations received by each patent by the application year and by the technology classification.[17]

3.2.2 Other Control Variables

We follow previous studies in adopting several control variables for innovation in the regression analysis. These variables include firm size, the lagged effect of R&D expenditures, firm leverage, firm performance, and firm value. Bhattacharya and Bloch (2004) find that an increment in innovative activities is accompanied by an increment in firm size. By contrast, Shefer and Frenkel (2005) argue that there is a negative relation between firm size and R&D expenditure. Thus, we measure total assets and net sales as proxies for the firm's size.

Hall (2002) finds that R&D-intensive firms use less debt financing because R&D investment has greater uncertainty and less collateral. Studies also find that the availability of financing influences R&D expenditures (Brown, Fazzari, and Petersen, 2009; Brown et al., 2012, and Hsu et al., 2014). Thus, we adopt the debt ratio, which is the total liability divided by total assets, to measure the firm's leverage.

Hitt, Hoskisson, Ireland, and Harrison (1991) suggest that when a firm's profitability increases, managers will become more risk-adverse and reduce intangible investment. More recently, Greve (2003) and Chang et al. (2019) also find the same results. Hence, we adopt Return On Assets (ROA), which is the Earnings Before Interest, Taxes, Aepreciation, and Amortization (EBITDA) divided by the average of total assets, to measure a firm's performance.

Tobin's Q is the market value of equity plus the book value of long-term and short-term debts, divided by book assets. Tobin's Q is usually used as the financial market-based measure of a firm's performance (Wernerfelt and Montgomery, 1988). Connolly and Hirschey (2005) adopt Tobin's Q to evaluate the firm's value based on R&D expenditures and show that larger firms have a greater valuation effect from R&D. Aghion et al. (2013) also use Tobin's Q to control for the influence of a firm's market value on innovation.

17 The technology classification of the PATSTAT database is based on the International Patent Classification (IPC) system. Hall et al. (2001) classify the 3-digit IPC code into 6 main industrial categories and use the simulated cumulated lag distribution of each category to calculate the truncation adjusted citations.

R&D expenditure usually exhibits a cumulative effect, and previous studies suggest using lagged R&D expenditure or lagged R&D intensity as the variable to explain the innovation output such as patent count, patent citations, or patent adjusted citations (Artz, Norman, Hatfield, and Cardinal, 2010; Beck-Blease, 2011; Kong, 2020). Griliches (1990) finds that there is a lagged relation between patent and R&D expenditure. Artz et al. (2010) examine the effect of R&D, patent, and product innovation on the firm performance and consider the time lag effect for these variables in their regression model. In particular, Artz et al. (2010) set R&D as invested at year *t-3* whereas the patent is granted at year *t-2* and thus they define the time lag between R&D and patent as about one year. In addition, Beck-Blease (2011) and Kong (2020) use lag R&D one year in explaining the patent output. Thus, following prior literature, we use all control variables and R&D expenditure in year *t-1* to explain the patent adjusted citations in year *t*.[18] Appendix Table A1 shows the definitions of all variables.

3.3 Methodology

3.3.1 Intra-industry Analysis and Inter-industry Analysis

We could directly and simply examine the innovation of the approved biopharmaceutical firms before and after the Biopharmaceutical Act to show the impact of the Biopharmaceutical Act. However, this methodology may neglect endogeneity problems, which means that changes in innovation may result from omitted variables bias, such as changes in the macroeconomic environment and other unobserved factors.[19] To eliminate the endogeneity concern, we identify control firms which have characteristics similar to those of approved biopharmaceutical firms (treated firms), and then compare the difference in innovation between these two groups.[20] Specifically, we perform an intra-

18 We follow previous studies (Aghion et al., 2013; Becker-Blease, 2011) and use the patent application date to identify the year of the patent. This can reduce the time gap problem between innovation input and innovation output because there are usually 2 or 3 years between the patent application date and the publication (or granted) date. Therefore, several empirical studies (Aghion et al., 2013; Chang, Fu, Low, and Zhang, 2015; Chang et al., 2019) use the contemporaneous R&D to explain the patent number or patent citations without considering the time lag between R&D and patent.

19 For example, unapproved biopharmaceutical firms may have the same innovation effect after Biopharmaceutical Act as the approved biopharmaceutical firms. Thus, we cannot infer that the Biopharmaceutical Act improves the innovation of approved biopharmaceutical firms.

20 This is the concept of Difference-in-difference (DID) method, which is widely used to deal with the endogeneity problem.

industry analysis, which examines the effect of Biopharmaceutical Act by comparing approved firms with unapproved firms (control firms) in the biopharmaceutical industry since only approved firms receive the benefits of the Act.

In addition, we conduct an inter-industry analysis by comparing high-tech firms and approved biopharmaceutical firms to confirm the effectiveness of policy. In Taiwan, the Biopharmaceutical Act grants tax credits only to biopharmaceutical firms, whereas the Statute for Upgrading Industries (SUI)（促進產業升級條例）, established in 1991, provides tax credits for all firms.[21] Yang et al. (2012) investigate the SUI and find that the tax credits have more effect on R&D for industries with greater R&D intensity. Based on this finding, Yang et al. (2012) suggest that the government should establish various tax credits across industries. In Taiwan, the Biopharmaceutical and high-tech industries are respective the first and second highest R&D intensity industries during the period 2007 to 2017.[22] Brown et al. (2017) argue that industries with greater R&D intensity are more likely to exhibit innovation underinvestment. The Biopharmaceutical Act is established to grant tax credits to the biopharmaceutical industry rather than other industries. Therefore, we choose the high-tech industry for comparison. Since the SUI grants all industries the same preferential tax treatment, comparing the Biopharmaceutical and high-tech industries helps to confirm the effectiveness of the Biopharmaceutical Act, which grants tax credits only to biopharmaceutical firms.

3.3.2 Propensity Score Matching (PSM)

To conduct the intra-industry and the inter-industry analyses, we adopt PSM to identify suitable control firms and prevent sample selection bias for treated firms. Introduced by Rosenbaum and Rubin (1983), PSM is a widely used technique for finding control firms which have characteristics similar to those of treated firms. This method ensures that estimation bias is greatly reduced by comparing the outcome of innovation across treated and control firms.

Previous studies generally use logistic regression to estimate the propensity score

21 The SUI is implemented from 1991 to 2019 whereas the Biopharmaceutical Act is implemented from 2007 to 2021.

22 R&D intensity, the ratio of R&D expenditures to total assets, for the Biopharmaceutical and high-tech industries is 4.08% and 3.04%, respectively.

for binary treatment (Rosenbaum and Rubin, 1983; Caliendo and Kopeinig, 2008). The propensity score is the predicted probability of a firm, $P = Pr(D|X)$, given a vector of observed predictors X, where D equals one if the firm is an approved biopharmaceutical firm and zero otherwise. After the estimation of the propensity score of each firm, we adopt the nearest neighbor matching method to find the control firms for the treated firms. Dehejia and Wahba (2002) allow control firms to be matched more than one because of the substantial difference in sample size between treated firms and untreated firms.[23] We select firms which have the nearest propensity score to the treated firm in each year to be control firms. In addition, to consider the sample size effect, we also choose firms which have the second, third, and fourth-nearest propensity scores to the treated firms to be control firms.

For the intra-industry analysis, we use the data of the year before the approval year to find control firms because the approval year (i.e. the event year) of each approved biopharmaceutical firm is different. We use the logistic regression to estimate the propensity score and then use the pre-event total assets, ROA, Tobin's Q, and R&D intensity as the explanatory variables in the logistic regression. In addition, for the inter-industry comparison, we use a similar concept to identify control group firms from the high-tech industry.

3.3.3 Difference-in-differences (DID) Estimator

We apply the DID approach to examine the effect of Biopharmaceutical Act on innovation because previous studies argue that DID is a useful instrument for evaluating the impact of certain policies which may only influence one part of the population (Blundell and Costa-Dias, 2009; Buckley and Shang, 2002; Lechner, 2011; Heckman, Ichimura, and Todd, 1997). The DID approach helps to eliminate the endogeneity problem because it assumes that unmeasured factors, such as the changes in economic conditions or other unobservable effects, affect both treated and control groups in similar ways. The DID approach can thus reduce the influence of other factors that may contaminate our treatment of the effect of the Biopharmaceutical Act on innovation.

Following past literature on the basic DID approach, we first calculate the DID estimator. In our paper, the DID estimator calculates the effect of the Biopharmaceutical Act by estimating the difference in average innovation measures before and after the

23 Lane, Looney, and Wansley (1986) use three matched firms for one treated firm to avoid possible estimation bias.

approval of the Biopharmaceutical Act for both treated firms and control firms, and then comparing the difference between these two groups. Control firms are found using the PSM procedure. In this study, we have two control groups, one for the intra-industry and the other for inter-industry analyses. Finally, we use the *t* statistic to examine the significance of the DID estimator. The significance of the DID estimator can be used to explain that the innovation in approved biopharmaceutical firms is significantly different from the innovation in control firms (i.e. unapproved biopharmaceutical firms or high-tech firms) after the Biopharmaceutical Act.

3.3.4 Difference-in-differences (DID) Regression

The DID estimator may not be sufficient to explain the influence of the Biopharmaceutical Act because it does not consider the heterogeneous dynamics from other variables (Buckley and Shang, 2002). In addition, most previous studies conduct only DID regressions and do not use the DID estimator. Thus, we follow previous studies (Blundell and Costa-Dias, 2009; Buckley and Shang, 2002; Lechner, 2011) to simply incorporate possible factors into the linear regression to estimate the influence of the Biopharmaceutical Act.

The DID regression is:

$$Y_{i,t} = \alpha_0 + \beta \cdot After_t + \delta \cdot Treatment_i + \gamma \cdot After_t \times Treatment_i + \pi \cdot Control\ variables_{i,t} + Year\ fixed\ effect + \varepsilon_{i,t}, \quad (1)$$

where $Y_{i,t}$ denotes the measure of innovation of firm i in year t; $After_t$ = 1 if the firm is in or after the approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is approved according to the Biopharmaceutical Act and 0 otherwise. The time period of this regression is from 2002 to 2017.[24]

We respectively use R&D intensity and patent adjusted citations to measure the innovation activities in the regressions. We use firm size (natural logarithm of total assets; Huang, 2019), lagged R&D expenditure (pre-year R&D expenditure), ROA, and debt ratio to explain the R&D investment (i.e. R&D intensity). When the patent adjusted citations are the innovation measure, we follow Lerner (1994) and Becker-Blease (2011) and use

24 All results for DID regressions control for the year fixed effect. To save space, we do not show the results for the year fixed effect in the tables.

the natural logarithm of 1+adjusted patent citations, LN (1+adjusted patent citation), as the dependent variable because a high proportion of the sample has a value of zero for the adjusted patent citations. To explain the adjusted patent citation, we use the natural logarithm of lagged net sales, lagged R&D expenditure, and lagged Tobin's Q as control variables.[25] The coefficient γ of interaction term, $After_t \times Treatment_i$ is used to test whether the Biopharmaceutical Act changes innovation for approved biopharmaceutical firms. If the Biopharmaceutical Act improves innovation for approved biopharmaceutical firms, γ will be significantly positive.

4. Empirical Results

4.1 Summary Statistics

Table 1 presents the descriptive statistics, including the mean and median of all variables, for the four groups. The approved biopharmaceutical firms include only the data of biopharmaceutical firms in the year of approval. The other three groups: unapproved biopharmaceutical firms, biopharmaceutical industry, and high-tech industry, comprise firm-year observations from 2007 to 2017.

Table 1 Descriptive Statistics

Variables	Approved Biopharmaceutical Firms		Unapproved Biopharmaceutical Firms		Biopharmaceutical Industry		High-tech Industry	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Patent	0.09	0.00	0.21	0.00	0.19	0.00	3.25	0.00
Adjusted Citation	0.04	0.00	0.09	0.00	0.08	0.00	1.07	0.00
R&D Expenditure	121.63	76.48	66.09	26.30	80.40	31.89	455.74	60.76
R&D intensity (%)	19.10	9.86	4.51	2.79	7.60	3.66	4.67	2.52

25 These control variables are incorporated into regressions following previous studies (Klassen, Pittman, Reed, and Fortin, 2004; Becker-Blease, 2011; Aghion et al., 2013; Chang et al., 2019). In addition, we consider the lagged effect for the patent adjusted citations because the innovation process takes time from the R&D input to patent application. Thus, following prior literature, we relate all control variables in year *t-1* to patent adjusted citations in year *t*.

Table 1 Descriptive Statistics (cont.)

Variables	Approved Biopharmaceutical Firms		Unapproved Biopharmaceutical Firms		Biopharmaceutical Industry		High-tech Industry	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Total Assets	1,176.30	609.74	2,262.25	1,099.15	1,970.91	917.59	14,979.32	2,342.30
Debt Ratio (%)	19.76	9.64	36.38	34.30	31.86	29.16	44.34	39.60
Net Sales	108.21	21.19	1,442.01	692.92	1,074.53	411.20	17,141.92	2,006.76
ROA	-18.23	-12.87	-0.21	8.67	-4.71	5.30	8.53	8.95
Tobin's Q	4.32	2.00	1.69	1.23	2.24	1.31	1.13	0.86
N	85	85	1,311	1,311	1,817	1,817	11,309	11,309

Note: This table shows the descriptive statistics of the variables for the four groups. Except for observations (N), all numbers represent the mean of the variable. The first group consists of approved biopharmaceutical firms, which are the observations of biopharmaceutical firms at the year of approval (only the event year). Unapproved biopharmaceutical firms are the firm-year observations of biopharmaceutical firms which are not approved by the Biopharmaceutical Act, from 2007 to 2017. Biopharmaceutical industry and high-tech industry are the firm-year observations from 2007 to 2017. All variables are defined in Appendix Table A1.

First, in the biopharmaceutical industry, we find that the approved biopharmaceutical firms have smaller total assets, debt ratio, net sales, ROA, but higher Tobin's Q than unapproved biopharmaceutical firms. In addition, approved biopharmaceutical firms have higher R&D expenditure and R&D intensity, but lower patent numbers and patent adjusted citations than unapproved biopharmaceutical firms. The median of patent and patent adjusted citation is zero, implying that most biopharmaceutical firms do not obtain innovation output such as patents. The median of R&D expenditure and R&D intensity is lower than the mean ones in the biopharmaceutical firms, implying only some or few biopharmaceutical firms may infuse greater R&D expenditures while most biopharmaceutical firms put relatively low amounts of money into R&D activities. Accordingly, compared with unapproved biopharmaceutical firms, approved biopharmaceutical firms tend to be smaller in firm size, leverage, and operating performance, but have higher firm value and higher innovation input but lower innovation output.

Second, in the inter-industry comparison, firms in the biopharmaceutical industry have smaller firm size, lower leverage, net sales, operating performance, and higher firm value than firms in the high-tech industry. In addition, compared with those in high-tech industry, firms in the biopharmaceutical industry have lower patent numbers, patent adjusted citations, and R&D expenditure, i.e. lower innovation input and output. However, firm sizes (i.e. total asset and/or net sales) of the biopharmaceutical industry are much smaller than those of firms in the high-tech industry, giving biopharmaceutical firms a higher proportion of R&D expenditure to firm size.

4.2 Effectiveness of PSM

To examine whether PSM helps to prevent the selection bias problem, we compare the pre-event firm characteristics between the treated firms (i.e. approved biopharmaceutical firms) and control firms. Table 2 presents the comparison of the pre-event firm characteristics between these two groups. The data of firm characteristics are at year *t-1* where *t* is the approval year of the treated firms. This table shows one, two, three, and four control firms which have the first, second, third, and fourth-nearest propensity scores to the treated firms.

In Table 2, Panel A shows the comparison between approved biopharmaceutical firms and unapproved biopharmaceutical firms. In the scenario of one control firm, all characteristics for the treated firms and control firms are not significantly different. Except for the ROA for the second, third, and fourth control firms, other characteristics of these firms are also not significantly different. Accordingly, among the unapproved biopharmaceutical firms, the control firms selected by PSM are quite similar to the approved biopharmaceutical firms. Panel B of Table 2 shows the comparison between approved biopharmaceutical firms and high-tech firms. Among the high-tech firms, the control firms selected by PSM are similar to the treated firms in ROA and R&D intensity. [26] Overall, by assuring that the pre-event firm characteristics of the treated firms and control firms are similar, we confirm that PSM alleviates the sample selection problem of control firms.

26 Since the firm characteristics in different industries are quite different, we do not obtain similar results for total assets and Tobin's Q.

Table 2 Effectiveness of Propensity Score Matching

Panel A Comparison of Firm Characteristics between Approved Biopharmaceutical Firms and Unapproved Biopharmaceutical Firms

	One Matched Firm			Two Matched Firms			Three Matched Firms			Four Matched Firms		
	Treated	Control	Diff.	Treated	Control	Diff.	Treated	Control	Diff.	Treated	Control	Diff.
N	68	68		68	136		68	204		68	272	
Total Assets	862.21	819.55	42.66 (0.54)	862.21	827.48	34.73 (0.53)	862.21	861.47	0.74 (0.99)	862.21	848.22	13.99 (0.78)
ROA	-19.78	-15.02	4.76 (0.27)	-19.78	-12.54	7.24* (0.05)	-19.78	-10.61	9.17*** (0.01)	-19.78	-9.96	9.82*** (0.00)
Tobin's Q	2.75	2.34	0.40 (0.61)	2.75	2.14	0.61 (0.40)	2.75	2.11	0.64 (0.35)	2.75	2.15	0.60 (0.37)
R&D intensity (%)	14.32	15.17	0.85 (0.64)	14.32	14.37	0.05 (0.97)	14.32	13.96	0.36 (0.76)	14.32	13.12	1.20 (0.31)

Panel B Comparison of Firm Characteristics between Approved Biopharmaceutical Firms and High-tech Firms

	One Matched Firm			Two Matched Firms			Three Matched Firms			Four Matched Firms		
	Treated	Control	Diff.	Treated	Control	Diff.	Treated	Control	Diff.	Treated	Control	Diff.
N	68	68		68	136		68	204		68	272	
Total Assets	862.21	722.38	139.83* (0.05)	862.21	681.46	180.75** (0.01)	862.21	683.07	179.14** (0.01)	862.21	691.62	170.59** (0.01)
ROA	-19.78	-19.13	0.66 (0.81)	-19.78	-18.55	1.23 (0.57)	-19.78	-18.26	1.52 (0.48)	-19.78	-16.97	2.81 (0.19)
Tobin's Q	2.75	1.84	0.90 (0.10)	2.75	1.78	0.97* (0.08)	2.75	1.73	1.02* (0.07)	2.75	1.74	1.01* (0.08)
(R&D/TA)*100	14.32	17.95	3.63 (0.14)	14.32	18.55	4.22** (0.02)	14.32	16.65	2.33 (0.15)	14.32	16.63	2.30 (0.16)

Note: This table presents the comparison of pre-event firm characteristics between the approved biopharmaceutical firms and control firms. The data of firm characteristics are at year *t-1* where *t* is the approval year of treated firms. This table shows one, two, three and four control firms which have the first, second, third, and fourth-nearest propensity scores with the treated firms. The variables are defined in Table 1. Panel A shows the comparison between approved biopharmaceutical firms and unapproved biopharmaceutical firms. Panel B shows the comparison between approved biopharmaceutical firms and high-tech firms. Diff. is the mean difference of variable (shown in absolute value) between the treated firms and control firms. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

4.3 Intra-industry Analysis

4.3.1 Difference-in-differences Estimator (DID Estimator)

Table 3 presents the DID estimator of innovation for intra-industry analysis. In order to consider the time span effect of the Biopharmaceutical Act, we consider the time interval of the pre-event and post-event year from (*t*-1, *t*+1) to (*t*-3, *t*+3) where t is the event year, i.e. the approval year, when the biopharmaceutical firm is approved by the Biopharmaceutical Act. Panel A and B present the DID estimator of the R&D investment and the DID estimator of the patent adjusted citations, respectively.

Table 3 DID Estimator: Intra-industry Analysis

Panel A: DID Estimator of R&D Investment: Intra-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Treated	14.3224	14.7030	0.3806	13.5214	14.6223	1.1010	13.0075	13.4002	0.3927
			(0.8686)			(0.5928)			(0.8183)
Control 1	15.1741	10.3605	-4.8135**	13.6871	10.7748	-2.9123	11.8360	10.5049	-1.3311
			(0.0222)			(0.1002)			(0.3658)
Control 2	14.3681	10.5547	-3.8134**	12.4338	10.1346	-2.2992*	10.9985	9.7941	-1.2043
			(0.0216)			(0.0685)			(0.2863)
Control 3	13.9605	11.2267	-2.7338**	11.6300	10.8426	-0.7875	10.3005	10.3891	0.0886
			(0.0392)			(0.4661)			(0.9234)
Control 4	13.1208	10.3647	-2.7561**	11.2082	10.1346	-1.0736	10.2415	9.7688	-0.4726
			(0.0231)			(0.2412)			(0.5553)
Diff.1	-0.8517	4.3425	5.1942**	-0.1657	3.8476	4.0133*	1.1715	2.8953	1.7238
			(0.0394)			(0.0956)			(0.3540)
Diff.2	-0.0458	4.1483	4.1941*	1.0876	4.4877	3.4002	2.0091	3.6061	1.5970
			(0.0646)			(0.1148)			(0.3541)
Diff.3	0.3619	3.4763	3.1144	1.8914	3.7798	1.8884	2.7070	3.0111	0.3041
			(0.1319)			(0.3653)			(0.8500)
Diff.4	1.2016	4.3383	3.1367	2.3132	4.4877	2.1745	2.7661	3.6314	0.8653
			(0.1240)			(0.2695)			(0.5662)

Panel B: DID Estimator of Adjusted Patent Citation: Intra-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Treated	0.0253	0.0648	0.0395	0.0348	0.0477	0.0129	0.0689	0.0796	0.0107
			(0.2171)			(0.5468)			(0.7261)

Table 3 DID Estimator: Intra-industry Analysis (cont.)

Panel B: DID Estimator of Adjusted Patent Citation: Intra-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Control 1	0.1224	0.0219	-0.1004	0.0617	0.0150	-0.0467	0.0099	0.0158	0.0060
			(0.1188)			(0.2750)			(0.7092)
Control 2	0.1651	0.0162	-0.1489***	0.0685	0.0128	-0.0557*	0.0300	0.0289	-0.0011
			(0.0068)			(0.0549)			(0.9294)
Control 3	0.1270	0.0176	-0.1094***	0.0585	0.0266	-0.0319	0.0419	0.0483	0.0064
			(0.0043)			(0.1624)			(0.6652)
Control 4	0.1239	0.0207	-0.1033***	0.0687	0.0356	-0.0331	0.0670	0.0566	-0.0105
			(0.0013)			(0.1385)			(0.6643)
Diff.1	-0.0971	0.0429	0.1400**	-0.0269	0.0327	0.0596	0.0590	0.0638	0.0048
			(0.0480)			(0.2044)			(0.8852)
Diff.2	-0.1398	0.0486	0.1884***	-0.0337	0.0349	0.0686**	0.0389	0.0507	0.0118
			(0.0024)			(0.0499)			(0.7213)
Diff.3	-0.1017	0.0472	0.1489***	-0.0237	0.0211	0.0448	0.0270	0.0313	0.0043
			(0.0024)			(0.1045)			(0.8934)
Diff.4	-0.0986	0.0442	0.1428***	-0.0339	0.0121	0.0460	0.0018	0.0230	0.0212
			(0.0013)			(0.1052)			(0.5759)

Note: This table presents the DID estimator of innovation for intra-industry analysis. Panels A and B present the DID estimator of the R&D investment and the DID estimator of adjusted patent citations, respectively. *t* is the event year, i.e. the year in which the Biopharmaceutical firm is approved by the Biopharmaceutical Act. Treated represents the treated firms, i.e. approved biopharmaceutical firms. Control 1, Control 2, Control 3, and Control 4 respectively represent one, two, three, and four control firms matched to each treated firm. The control firms in the intra-industry analysis are unapproved biopharmaceutical firms. Diff.1, Diff.2, Diff.3, and Diff.4 represent the mean difference of variables between Treated and Control 1, Control 2, Control 3, and Control 4, respectively. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

In Panel A of Table 3, the approved biopharmaceutical firms do not change R&D investment significantly after the approval year. However, when we consider the time interval (*t*-1, *t*+1), the unapproved biopharmaceutical firms exhibit significantly lower R&D investment after the approval year. The DID estimators of the R&D investment for one and two control matched firms are significant. This result implies that compared with unapproved biopharmaceutical firms, approved biopharmaceutical firms have a significantly higher proportion of R&D expenditures to total assets after the

Biopharmaceutical Act.

Panel B of Table 3 shows that approved biopharmaceutical firms do not significantly change their adjusted patent citations, while unapproved biopharmaceutical firms experience significantly reduced adjusted patent citations for the time interval (t-1, t+1). In this short time interval, the DID estimators of adjusted patent citations are significantly positive, implying that the approved biopharmaceutical firms have significantly higher innovation output than unapproved biopharmaceutical firms after the Biopharmaceutical Act.

Accordingly, the results of the DID estimators show that compared to unapproved biopharmaceutical firms, the Biopharmaceutical Act encourages approved biopharmaceutical firms to increase their input into innovation activities, leading to higher innovation quality. In addition, both panels of Table 3 show that there are no significant DID estimators for the time intervals (t-*2*, t+*2*) and (t-*3*, t+*3*), implying that the influence of the Biopharmaceutical Act on innovation input and output has only a short-term effect. This result is consistent with David et al. (2000), who find that the recipients of tax credits tend to concentrate on projects with short-term prospects.

4.3.2 Difference-in-differences Regression (DID Regression)

To obtain more accurate results, we conduct the DID regression by additionally considering the heterogeneous dynamics of other variables for innovation measures. Table 4 shows the DID regression results for the intra-industry analysis. Panel A of Table 4 shows the DID regression results for R&D investment. For matched firms the significantly negative coefficients of *After* show that all biopharmaceutical firms reduce their R&D investments after the Biopharmaceutical Act. In addition, the significantly negative coefficients of *Treatment* indicate that the approved biopharmaceutical firms on average have lower R&D investments than the unapproved biopharmaceutical firms. Further, the significantly positive coefficients of the interaction term, *After*×*Treatment*, show that compared with unapproved biopharmaceutical firms, approved biopharmaceutical firms have significantly higher R&D investments after the approval. By combining the coefficient results of *Treatment* and *After*×*Treatment*, we find that relative to control firms, the Biopharmaceutical Act encourages the group of treated firms, which have lower R&D intensity, to improve their R&D input. Accordingly, unlike the unapproved biopharmaceutical firms, the approved biopharmaceutical firms, which respond to the exogenous shock of the Biopharmaceutical Act and receive its benefits, are induced to improve their input into innovation activities.

Table 4 DID Regression Result: Intra-industry Analysis

Panel A: DID Regression Results for R&D Investment: Intra-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-2.0664**	-1.9547**	-2.0441***	-1.9966***	-2.2199***	-2.1781***	-1.7430***	-1.7228***
	(0.0232)	(0.0312)	(0.0012)	(0.0016)	(0.0000)	(0.0000)	(0.0001)	(0.0001)
$Treatment_i$	-3.4668***	-2.7768***	-2.6599***	-2.1885***	-2.6303***	-2.1488***	-2.0912***	-1.7150***
	(0.0000)	(0.0009)	(0.0001)	(0.0013)	(0.0000)	(0.0007)	(0.0003)	(0.0032)
$After_t \times Treatment_i$	3.9568***	3.9036***	3.5181***	3.5151***	3.1617***	3.1731***	2.8590***	2.8811***
	(0.0003)	(0.0004)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0002)
$LN\ (TA)_t$	-1.4952***	-1.4720***	-1.2323***	-1.2478***	-0.8971***	-0.9764***	-0.6687***	-0.7396***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RD_{t-1}	0.1601***	0.1623***	0.2039***	0.2060***	0.2442***	0.2461***	0.2701***	0.2716***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.4388***	-0.4344***	-0.3842***	-0.3813***	-0.3642***	-0.3604***	-0.3367***	-0.3337***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$Debt\ Ratio_t$		0.0424***		0.0326***		0.0318***		0.0259***
		(0.0006)		(0.0009)		(0.0002)		(0.0003)
Observations	1,350	1,350	2,019	2,019	2,689	2,689	3,474	3,474
Adjusted R^2	0.6287	0.6317	0.6179	0.6198	0.6141	0.6161	0.5989	0.6003

Panel B: DID Regression Results for Adjusted Patent Citations: Intra-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0210	-0.0177	-0.0381**	-0.0378**	-0.0145	-0.0134	0.0016	0.0026
	(0.2324)	(0.3256)	(0.0169)	(0.0211)	(0.2616)	(0.3065)	(0.8751)	(0.0507)
$Treatment_i$	0.0102	0.0199	-0.0153	-0.0084	-0.0047	0.0061	0.0026	0.0148
	(0.4913)	(0.2118)	(0.3315)	(0.6229)	(0.7443)	(0.6924)	(0.8443)	(0.2905)
$After_t \times Treatment_i$	-0.0006	-0.0074	0.0169	0.0132	0.0027	-0.0050	-0.0071	-0.0146
	(0.9769)	(0.7223)	(0.4215)	(0.5529)	(0.8860)	(0.8065)	(0.6848)	(0.4246)
$LN\ (1+NetSales_{t-1})$	0.0026*	0.0036**	0.0004	0.0013	0.0004	0.0020	-0.0001	0.0017
	(0.0813)	(0.0262)	(0.7847)	(0.4355)	(0.7384)	(0.1607)	(0.9222)	(0.1775)
RD_{t-1}	0.0006	0.0007*	0.0006	0.0007*	0.0005	0.0007*	0.0006*	0.0009***
	(0.1040)	(0.0713)	(0.1440)	(0.0977)	(0.2244)	(0.0895)	(0.0671)	(0.0098)
$Tobin's\ Q_{t-1}$		-0.0006		-0.0008		-0.0003		-0.0008
		(0.6629)		(0.5914)		(0.8329)		(0.5517)

Table 4 DID Regression Result: Intra-industry Analysis (cont.)

Panel B: DID Regression Results for Adjusted Patent Citations: Intra-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Observations	903	858	1,364	1,298	1,817	1,725	2,358	2,244
Adjusted R^2	0.0043	0.0053	0.0156	0.0142	0.0142	0.0148	0.0134	0.0147

Note: This table presents the panel regression results of the intra-industry analysis, including regression of R&D investment and adjusted citations for one, two, three and four matching control firms. The dependent variable of Panel B is the natural logarithm of 1+adjusted patent citation, i.e. LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms and the control firms are unapproved biopharmaceutical firms. The definitions of variables are presented in Appendix Table A1. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The results of other control variables in Panel A of Table 4 are consistent with economic intuition and findings of previous studies. First, the coefficient of the natural logarithm of total assets is significantly negative, meaning that the R&D investment of firms increases when firm size decreases. This result confirms that small firms are more engaged in innovation activities, which is consistent with Shefer and Frenkel (2005) and Hægeland and Møen (2007). Second, the significantly positive lagged R&D expenditure indicates the accumulative effect of R&D, which is consistent with Chan, Lakonishok, and Sougiannis (2001). Third, R&D investment and ROA are negatively correlated because R&D is spent in the income statement.

Panel B of Table 4 shows no significant coefficients of *After*, *Treatment*, and *After*×*Treatment*, indicating that the established Biopharmaceutical Act does not have any effect on the adjusted patent citations of approved biopharmaceutical firms. This result is not consistent with the result of the DID estimator, which shows the positive effect of the Biopharmaceutical Act. To explain the inconsistent outcomes, Buckley and Shang (2002) argue that the DID estimator may not be sufficient to capture the results of the study because this method neglects the heterogeneous dynamics of other important variables.

Accordingly, the DID regression, which incorporates other control variables, may obtain more accurate results than the DID estimator. Thus, the results of this study showing that the Biopharmaceutical Act does not influence the innovation quality of the approved biopharmaceutical firms. In sum, the Biopharmaceutical Act encourages biopharmaceutical firms to expand innovation input but does not improve their innovation quality.

4.3.3 Subsample Analysis of Intra-industry

The subsection considers two intra-industry subsample analyses. By grouping firms with similar characteristics, these analyses may help to further realize which groups may dominate the main results of the sample. First, we consider that the subsamples are divided by different operating items. The different operating items in the biopharmaceutical industry may have different effects on the Biopharmaceutical Act's encouragement of innovation activities. In Taiwan, the biopharmaceutical industry is usually divided into four groups: pharmaceuticals, medical equipment, applied biopharmaceutical, and others. The approved biopharmaceutical firms in our data include 66 pharmaceutical firms, 15 medical equipment firms and 2 applied biopharmaceutical firms. We divide the approved biopharmaceutical firms into two subgroups: pharmaceutical and non-pharmaceutical firms, because the sample of medical equipment and applied biopharmaceutical firms was too small for the DID regression.[27]

Table 5 shows the DID regression results for the intra-industry analysis of pharmaceutical and non-pharmaceutical firms. In Panels A.1 and A.2, the dependent variable is R&D investment. In Panels B.1 and B.2, the dependent variable is LN (1+adjusted patent citation). The coefficients of the interaction term, *After*×*Treatment*, for two, three and four matched firms of Panel A.1 are significantly positive but those of Panel A.2 are not significant. These results indicate that relative to unapproved pharmaceutical firms, the Biopharmaceutical Act encourages the approved pharmaceutical firms to increase R&D investment.

27 For the PSM exercise, the control firms are matched using the same operating items as the treated firms. Thus, the control firms for the approved pharmaceutical (non-pharmaceutical) firms are the unapproved pharmaceutical (non-pharmaceutical) firms.

Table 5 DID Regression Result of Intra-industry: Subsample Analysis for Different Operating Items

Panel A.1 DID Regression Results for R&D Investment in the Intra-industry Analysis: Pharmaceutical Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	1.0945	1.4489	0.1463	0.1518	0.5109	0.5106	0.3880	0.3965
	(0.2847)	(0.1552)	(0.6327)	(0.8323)	(0.3776)	(0.3779)	(0.4134)	(0.4032)
$Treatment_i$	0.9153	2.0482**	0.7319	1.0929	0.9790	0.9375	0.9550	0.7290
	(0.3179)	(0.0316)	(0.3308)	(0.1607)	(0.1545)	(0.1842)	(0.1278)	(0.2560)
$After_t \times Treatment_i$	1.2582	0.8770	1.9375**	1.8978*	1.5925*	1.5980*	1.7259**	1.7547**
	(0.2991)	(0.4671)	(0.0489)	(0.0536)	(0.0751)	(0.0742)	(0.0342)	(0.0313)
$LN\ (TA)_t$	-1.8671***	-1.9708***	-1.3008***	-1.3691***	-1.2887***	-1.2819***	-1.1806***	-1.1328***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RD_{t-1}	0.1215***	0.1265***	0.1423***	0.1425***	0.1733***	0.1731***	0.2153***	0.2139***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.5014***	-0.4894***	-0.4562***	-0.4529***	-0.4259***	-0.4262***	-0.3832***	-0.3855***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$Debt\ Ratio_t$		0.0603***		0.0193*		-0.0025		-0.0131*
		(0.0001)		(0.0760)		(0.7950)		(0.0996)
Observations	1,009	1,009	1,508	1,508	2,004	2,004	2,604	2,604
Adjusted R^2	0.6848	0.6896	0.6744	0.6749	0.6797	0.6795	0.6559	0.6561

Panel A.2 DID Regression Results for R&D Investment in the Intra-industry Analysis: Non-pharmaceutical Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	0.9667	0.9603	-0.4504	-0.4521	-0.5938	-0.5917	-0.4110	-0.4054
	(0.4181)	(0.4219)	(0.6327)	(0.6318)	(0.4698)	(0.4719)	(0.5408)	(0.5465)
$Treatment_i$	-0.7413	-0.7252	-1.0261	-1.0168	-0.7747	-0.7628	-0.3770	-0.3704
	(0.4625)	(0.4730)	(0.2624)	(0.2681)	(0.3809)	(0.3896)	(0.6336)	(0.6397)
$After_t \times Treatment_i$	-0.9789	-0.9027	-0.1675	-0.1932	-0.3556	-0.3896	-0.4983	-0.5708
	(0.4734)	(0.5110)	(0.8940)	(0.8788)	(0.7711)	(0.7521)	(0.6496)	(0.6051)
$LN\ (TA)_t$	-1.7651***	-1.7208***	-1.4264***	-1.4365***	-1.7012***	-1.7108***	-1.7368***	-1.7417***
	(0.0012)	(0.0018)	(0.0026)	(0.0026)	(0.0001)	(0.0001)	(0.0000)	(0.0000)

Table 5 DID Regression Result of Intra-industry: Subsample Analysis for Different Operating Items (cont.)

Panel A.2 DID Regression Results for R&D Investment in the Intra-industry Analysis: Non-pharmaceutical Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
RD_{t-1}	0.4421***	0.4450***	0.5135***	0.5125***	0.5375***	0.5363***	0.5680***	0.5652***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.1356***	-0.1351***	-0.1359***	-0.1359***	-0.1104***	-0.1102***	-0.0883***	-0.0885***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Debt $Ratio_t$		0.0101		-0.0029		-0.0031		-0.0072
		(0.5505)		(0.8553)		(0.8300)		(0.5431)
Observations	257	257	388	388	519	519	661	661
Adjusted R^2	0.563	0.5618	0.5586	0.5574	0.5334	0.5325	0.5319	0.5314

Panel B.1 DID Regression Results for Adjusted Patent Citations in the Intra-industry Analysis: Pharmaceutical Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	0.0194	0.0219	0.0278**	0.0291**	0.0216***	0.0225***	0.0179**	0.0183**
	(0.1653)	(0.1276)	(0.0117)	(0.0102)	(0.0076)	(0.0064)	(0.0104)	(0.0507)
$Treatment_i$	0.0349***	0.0415***	0.0252**	0.0308***	0.0287***	0.0345***	0.0270***	0.0316***
	(0.0035)	(0.0012)	(0.0209)	(0.0089)	(0.0014)	(0.0004)	(0.0020)	(0.0009)
$After_t \times Treatment_i$	-0.0135	-0.0193	-0.0160	-0.0206	-0.0150	-0.0198	-0.0141	-0.0198
	(0.3977)	(0.2494)	(0.2693)	(0.1795)	(0.2081)	(0.1177)	(0.2244)	(0.1097)
LN $(1+NetSales_{t-1})$	0.0007	0.0007	0.0009	0.0008	0.0009	0.0008	0.0013*	0.0012*
	(0.5029)	(0.5653)	(0.3316)	(0.4059)	(0.2445)	(0.3119)	(0.0579)	(0.0958)
RD_{t-1}	0.0000	0.0000	0.0006**	0.0005**	0.0005**	0.0005**	0.0005***	0.0005**
	(0.9018)	(0.9934)	(0.0298)	(0.0489)	(0.0116)	(0.0209)	(0.0072)	(0.0197)
Tobin's Q_{t-1}		-0.0003		-0.0004		-0.0004		0.0004
		(0.7849)		(0.6862)		(0.6309)		(0.6149)
Observations	676	651	1,013	980	1,358	1,321	1,777	1,720
Adjusted R^2	0.0142	0.0160	0.0212	0.0218	0.0221	0.0234	0.0324	0.0332

Table 5 DID Regression Result of Intra-industry: Subsample Analysis for Different Operating Items (cont.)

Panel B.2 DID Regression Results for Adjusted Patent Citations in the Intra-industry Analysis: Non-pharmaceutical Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0093	-0.0051	-0.0093	0.0010	-0.0054	0.0024	-0.0136	-0.0081
	(0.7946)	(0.8923)	(0.7770)	(0.9759)	(0.8183)	(0.9233)	(0.5111)	(0.0507)
$Treatment_i$	-0.0046	-0.0089	-0.0129	-0.0163	-0.0050	-0.0124	-0.0133	-0.0175
	(0.8687)	(0.7724)	(0.6657)	(0.6228)	(0.8387)	(0.6486)	(0.5768)	(0.4986)
$After_i \times Treatment_i$	-0.0065	0.0013	-0.0100	-0.0014	-0.0073	0.0048	0.0000	0.0109
	(0.8666)	(0.9754)	(0.8105)	(0.9758)	(0.8330)	(0.8980)	(0.9996)	(0.7587)
LN (1+$NetSales_{t-1}$)	-0.0052	-0.0068*	-0.0076***	-0.0107***	-0.0068***	-0.0107***	-0.0063***	-0.0092***
	(0.1034)	(0.0653)	(0.0085)	(0.0018)	(0.0031)	(0.0002)	(0.0033)	(0.0006)
RD_{t-1}	-0.0006	-0.0005	-0.0016	-0.0020	-0.0007	-0.0013	-0.0004	-0.0006
	(0.6938)	(0.7309)	(0.2574)	(0.1968)	(0.4952)	(0.2618)	(0.6872)	(0.5561)
Tobin's Q_{t-1}		-0.0063		-0.0092*		-0.0080*		-0.0089**
		(0.2233)		(0.0997)		(0.0938)		(0.0495)
Observations	176	166	262	243	366	334	477	433
Adjusted R^2	0.0675	0.0631	0.1044	0.1106	0.0744	0.0852	0.0407	0.0528

Note: This table presents the panel regression results of the subsamples divided by different operating items, including pharmaceutical firms and non-pharmaceutical firms in the intra-industry. Panels A.1 and A.2 show the regression results that explain the R&D investment for pharmaceutical firms and non-pharmaceutical firms, respectively. Panels B.1 and B.2 show the regression results that explain the adjusted patent citations for these two subsamples. The dependent variable of Panels B.1 and B.2 is LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in the treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms, while control firms are unapproved biopharmaceutical firms. The definitions of variables are presented in Appendix Table A1. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The coefficients of Treatment in Panel B.1 of Table 5 are positive significantly. These results imply that in the group of pharmaceutical firms, the approved firms always have higher innovation quality (i.e. patent adjusted citation) than the unapproved firms. In addition, in both Panel B.1 and B.2, the coefficients of the interaction term,

After×*Treatment*, are not significant. These results show that for both pharmaceutical and non-pharmaceutical firms, the Biopharmaceutical Act does not have any effect on innovation quality.

The second subsample analysis is related to the level of a firm's R&D intensity. The level of a firm's R&D intensity appears to be relevant to the incentive effect of the Biopharmaceutical Act because the results in Table 4 show that the treated firms, which have lower R&D intensity, are more likely to be encouraged by the Biopharmaceutical Act. Therefore, we divide the sample into low and high R&D intensity groups. Table 6 shows the results of the DID regression for low and high R&D intensity firms in the intra-industry analysis.

Table 6 DID Regression Result of Intra-industry: Subsample Analysis for Different R&D Intensity Level

Panel A.1 DID Regression Result for R&D Investment in Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	1.3733	2.2328**	0.8936	1.3061*	0.9967*	1.3142**	0.9299**	1.1481**
	(0.1935)	(0.0310)	(0.6327)	(0.0596)	(0.0898)	(0.0236)	(0.0499)	(0.0150)
$Treatment_i$	-2.2599**	-0.4240	-1.5121**	0.1130	-1.2300*	0.0025	-0.7428	0.1777
	(0.0140)	(0.6495)	(0.0325)	(0.8764)	(0.0597)	(0.9970)	(0.2006)	(0.7659)
$After_t$ × $Treatment_i$	2.9642**	2.2799*	2.8348***	2.5107***	2.4333***	2.2252***	2.3672***	2.1840***
	(0.0164)	(0.0581)	(0.0027)	(0.0065)	(0.0052)	(0.0095)	(0.0023)	(0.0045)
$LN\ (TA)_t$	-1.6298***	-1.8108***	-1.1485***	-1.5388***	-1.1644***	-1.4693***	-0.9882***	-1.2245***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RD_{t-1}	0.1710***	0.1849***	0.2128***	0.2242***	0.2617***	0.2746***	0.2878***	0.2975***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.4561***	-0.4169***	-0.3771***	-0.3451***	-0.3382***	-0.3183***	-0.3015***	-0.2859***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Debt $Ratio_t$		0.0977***		0.0808***		0.0689***		0.0481***
		(0.0000)		(0.0000)		(0.0000)		(0.0000)
Observations	746	746	1,121	1,121	1,474	1,474	1,859	1,859
Adjusted R^2	0.5761	0.5999	0.5265	0.5475	0.5174	0.5322	0.4932	0.5021

Table 6 DID Regression Result of Intra-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel A.2 DID Regression Result for R&D Investment in Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-1.2504	-1.3138	-2.6875**	-2.5527**	-2.1872**	-2.0000**	-1.7754**	-1.4404*
	(0.4433)	(0.4196)	(0.6327)	(0.0301)	(0.0214)	(0.0327)	(0.0222)	(0.0601)
$Treatment_i$	2.8124*	2.4456*	2.1704*	1.7589	2.4529**	2.0608*	2.6533**	2.2893**
	(0.0561)	(0.0990)	(0.0911)	(0.1677)	(0.0366)	(0.0751)	(0.0135)	(0.0307)
$After_t \times Treatment_i$	-1.2792	-1.4119	0.3047	-0.2847	-0.1899	-0.8479	-0.5431	-1.2447
	(0.5014)	(0.4574)	(0.8514)	(0.8602)	(0.8980)	(0.5625)	(0.6877)	(0.3515)
$LN\ (TA)_t$	-1.2524**	-1.4187**	-1.1075***	-1.2407***	-1.2395***	-1.4262***	-1.0844***	-1.1568***
	(0.0286)	(0.0142)	(0.0069)	(0.0023)	(0.0002)	(0.0000)	(0.0001)	(0.0000)
RD_{t-1}	0.1344***	0.1330***	0.1671***	0.1727***	0.2057***	0.2070***	0.2513***	0.2480***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.4505***	-0.4484***	-0.4149***	-0.4124***	-0.3762***	-0.3733***	-0.3241***	-0.3276***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$Debt\ Ratio_t$		-0.0427*		-0.0674***		-0.0798***		-0.0764***
		(0.0723)		(0.0001)		(0.0000)		(0.0000)
Observations	520	520	775	775	1,049	1,049	1,406	1,406
Adjusted R^2	0.6598	0.6613	0.6445	0.6518	0.6456	0.656	0.6185	0.6295

Panel B.1 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	0.0218	0.0261	0.0282**	0.0340**	0.0199*	0.0234**	0.0119	0.0150
	(0.2603)	(0.2000)	(0.0423)	(0.0185)	(0.0542)	(0.0280)	(0.2128)	(0.0507)
$Treatment_i$	0.0299*	0.0363**	0.0282**	0.0363***	0.0299***	0.0372***	0.0232**	0.0271**
	(0.0521)	(0.0293)	(0.0248)	(0.0081)	(0.0038)	(0.0010)	(0.0264)	(0.0188)

Table 6 DID Regression Result of Intra-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel B.1 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t \times Treatment_i$	-0.0038	-0.0089	-0.0110	-0.0183	-0.0086	-0.0146	-0.0034	-0.0118
	(0.8529)	(0.6838)	(0.5168)	(0.3114)	(0.5372)	(0.3275)	(0.8113)	(0.4365)
LN (1+$NetSales_{t-1}$)	0.0006	0.0004	0.0013	0.0012	0.0010	0.0010	0.0016*	0.0017*
	(0.6859)	(0.8091)	(0.2786)	(0.3223)	(0.2640)	(0.3203)	(0.0628)	(0.0707)
RD_{t-1}	0.0000	-0.0001	0.0001	0.0000	0.0002	0.0001	0.0003	0.0003
	(0.9282)	(0.8281)	(0.8892)	(0.9675)	(0.6504)	(0.7343)	(0.3944)	(0.5308)
Tobin's Q_{t-1}		-0.0006		-0.0002		-0.0005		0.0022
		(0.7524)		(0.8916)		(0.7378)		(0.1561)
Observations	505	480	765	728	1,031	984	1,294	1,229
Adjusted R^2	0.0102	0.0110	0.0162	0.0187	0.0186	0.0196	0.0318	0.0340

Panel B.2 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0003	-0.0002	0.0115	0.0118	0.0100	0.0110	0.0105	0.0101
	(0.9894)	(0.9916)	(0.5588)	(0.5568)	(0.4893)	(0.4572)	(0.3768)	(0.0507)
$Treatment_i$	0.0084	0.0092	-0.0185	-0.0218	-0.0051	-0.0072	-0.0033	-0.0013
	(0.6106)	(0.6049)	(0.3451)	(0.2996)	(0.7577)	(0.6831)	(0.8270)	(0.9348)
$After_t \times Treatment_i$	-0.0131	-0.0134	0.0006	0.0036	-0.0036	-0.0022	-0.0068	-0.0082
	(0.5537)	(0.5672)	(0.9824)	(0.8965)	(0.8708)	(0.9237)	(0.7398)	(0.6976)
LN (1+$NetSales_{t-1}$)	-0.0019	-0.0019	-0.0043***	-0.0049***	-0.0034***	-0.0043***	-0.0035***	-0.0035***
	(0.2042)	(0.2381)	(0.0077)	(0.0057)	(0.0075)	(0.0030)	(0.0018)	(0.0053)
RD_{t-1}	-0.0001	-0.0001	0.0001	0.0000	0.0001	-0.0001	-0.0001	-0.0001
	(0.8032)	(0.8450)	(0.8172)	(0.9608)	(0.8829)	(0.8145)	(0.8257)	(0.8592)

Table 6 DID Regression Result of Intra-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel B.2 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Tobin's Q_{t-1}		-0.0002		-0.0001		0.0001		-0.0002
		(0.8629)		(0.9398)		(0.9691)		(0.8376)
Observations	347	337	510	495	693	671	960	924
Adjusted R^2	0.0641	0.0589	0.0842	0.0831	0.0559	0.0566	0.0262	0.0268

Note: This table presents the panel regression results of the subsamples divided by different R&D intensity levels, including low R&D intensity firms and high R&D intensity firms. Panels A.1 and A.2 show the regression results that explain the R&D investment of low and high R&D intensity firms, respectively. Panels B.1 and B.2 show the regression results that explain the adjusted patent citation for these two subsamples. The dependent variable of Panels B.1 and B.2 is LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in the treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms and control firms are unapproved biopharmaceutical firms. The definitions of the variables are presented in Appendix Table A1. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A.1 of Table 6 shows that the coefficients of interaction term, *After*×*Treatment* are significant and positive. Panel A.2 of this table shows that this interaction term has no significant coefficients. These findings show that the approved biopharmaceutical firms with low R&D intensity are the group that captures the main results: this group is motivated more to increase innovation investment. In addition, the Biopharmaceutical Act does not motivate the biopharmaceutical firms with high R&D intensity to raise their innovation input. The subsample analysis findings for different R&D levels are consistent with Hægeland and Møen (2007), who find that R&D tax credit policy motivates low R&D firms more than high R&D firms because this policy decreases the marginal costs of R&D more for low R&D firms.

The coefficients of *Treatment* in Panel B.1 of Table 6 are positive and significant. These results indicate that in the group of low R&D intensity firms, the approved firms

always have higher innovation quality (i.e. adjusted patent citations) than the unapproved firms. In addition, in both Panel B.1 and B.2, the coefficients of the interaction term, *After*×*Treatment*, are not significant. These results show that for both low and high R&D intensity firms, the Biopharmaceutical Act does not have any effect on the innovation quality.

In sum, the results from pharmaceutical and low R&D intensity firms help to explain the influence of the Biopharmaceutical Act on R&D investment. These two subsample findings may have similar economic implications because Yang et al. (2012) find that pharmaceutical firms usually have low R&D intensity.[28] The pharmaceutical firms are more likely to have more serious R&D underinvestment than non-pharmaceutical firms because of higher risks and fewer successful cases of new medicine research, long periods required for innovations, and substantial investment necessaries. In addition, low R&D intensity firms tend to have greater R&D underinvestment. Thus, these findings for pharmaceutical and low R&D intensity firms imply that the firms with more serious R&D underinvestment problems receive greater encouragement from the Biopharmaceutical Act.

4.4 Inter-industry Analysis

To examine whether the Biopharmaceutical Act is effective only for biopharmaceutical firms rather than other industries, we choose the high-tech industry as the control industry because high-tech industry also has R&D intensity as high as that of biopharmaceutical firms in Taiwan.

4.4.1 Difference-in-differences Estimator (DID Estimator)

Table 7 presents the DID estimator of innovation for the inter-industry analysis. We also consider the possible continuous effect of the Biopharmaceutical Act and incorporate different time interval analyses in this table. Panel A and B present the DID estimator of the R&D investment and adjusted patent citations, respectively.

28 According to Yang et al. (2012), pharmaceutical firms usually have low R&D intensity because pharmaceutical firms generally produce generic drugs rather than patent drugs in Taiwan.

Table 7 DID Estimator: Inter-industry Analysis

Panel A: DID Estimator for R&D Investment: Inter-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Treated	14.3224	14.7030	0.3806	13.5214	14.6223	1.1010	13.0075	13.4002	0.3927
			(0.8686)			(0.5928)			(0.8183)
Control 1	17.9489	12.0816	-5.8673***	17.1562	11.8311	-5.3251**	17.0038	11.5033	-5.5005**
			(0.0067)			(0.0253)			(0.0305)
Control 2	18.5454	12.4521	-6.0932***	18.0979	12.6801	-5.4178**	16.4575	11.3838	-5.0738**
			(0.0027)			(0.0108)			(0.0141)
Control 3	16.6494	12.0499	-4.5995***	15.8808	12.0349	-3.8458**	14.8170	11.0165	-3.8004**
			(0.0018)			(0.0108)			(0.0109)
Control 4	16.6250	11.7890	-4.8361***	16.4159	11.5156	-4.9003***	15.0083	10.4198	-4.5885***
			(0.0002)			(0.0010)			(0.0019)
Diff.1	-3.6265	2.6214	6.2479***	-3.6349	2.7912	6.4261***	-3.9962	1.8970	5.8932***
			(0.0056)			(0.0030)			(0.0084)
Diff.2	-4.2230	2.2509	6.4739***	-4.5765	1.9422	6.5188***	-3.4500	2.0165	5.4665***
			(0.0019)			(0.0027)			(0.0039)
Diff.3	-2.3271	2.6531	4.9802**	-2.3594	2.5874	4.9468***	-1.8094	2.3837	4.1931***
			(0.0178)			(0.0084)			(0.0066)
Diff.4	-2.3027	2.9140	5.2167**	-2.8945	3.1067	6.0013***	-2.0007	2.9804	4.9812***
			(0.0153)			(0.0023)			(0.0038)

Panel B: DID Estimator for Adjusted Patent Citations: Inter-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Treated	0.0253	0.0648	0.0395	0.0348	0.0477	0.0129	0.0689	0.0796	0.0107
			(0.2171)			(0.5468)			(0.7261)
Control 1	0.3258	0.1355	-0.1902	0.0810	0.0927	0.0117	0.0675	0.0562	-0.0113
			(0.2517)			(0.8471)			(0.8743)
Control 2	0.4472	0.2254	-0.2218*	0.2933	0.1812	-0.1122	0.0818	0.0805	-0.0014
			(0.0606)			(0.2705)			(0.9762)
Control 3	0.4852	0.1749	-0.3103***	0.2827	0.1790	-0.1037	0.1420	0.1772	0.0353
			(0.0035)			(0.1852)			(0.4879)
Control 4	0.4164	0.1465	-0.2699***	0.2266	0.1454	-0.0813	0.1279	0.1516	0.0237
			(0.0081)			(0.1657)			(0.5809)
Diff.1	-0.3004	-0.0707	0.2297	-0.0462	-0.0450	0.0012	0.0013	0.0234	0.0220
			(0.1731)			(0.9851)			(0.7702)
Diff.2	-0.4219	-0.1606	0.2613**	-0.2585	-0.1334	0.1251	-0.0130	-0.0009	0.0121
			(0.0308)			(0.2313)			(0.8358)

Table 7 DID Estimator: Inter-industry Analysis (cont.)

Panel B: DID Estimator for Adjusted Patent Citations: Inter-industry Analysis

	t-1	*t*+1	Differences	*t*-2	*t*+2	Differences	*t*-3	*t*+3	Differences
Diff.3	-0.4599	-0.1101	0.3498***	-0.2479	-0.1313	0.1166	-0.0731	-0.0976	-0.0245
			(0.0014)			(0.1526)			(0.7009)
Diff.4	-0.3911	-0.0817	0.3094***	-0.1918	-0.0976	0.0942	-0.0590	-0.0720	-0.0130
			(0.0034)			(0.1337)			(0.8247)

Note: This table presents the DID estimator of innovation for the inter-industry analysis. Panels A and B present the DID estimator of R&D investment and the DID estimator of adjusted patent citations, respectively. *t* is the event year, i.e. the year in which the Biopharmaceutical firm is approved by the Biopharmaceutical Act. Treated represents the treated firms, i.e. approved biopharmaceutical firms. Control 1, Control 2, Control 3, and Control 4 respectively represent one, two, three, and four control firms to each treated firm. The control firms in the inter-industry analysis are high-tech firms. Diff.1, Diff.2, Diff.3, and Diff.4 represent the mean difference in the variables between Treated and Control 1, Control 2, Control 3, and Control 4 respectively. Numbers in the parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel A of Table 7 shows that the high-tech firms significantly decrease their R&D investment after the approval year although the approved biopharmaceutical firms do not change the proportions of R&D. The significantly positive DID estimators of R&D investment show that after the Biopharmaceutical Act, compared with high-tech firms, approved biopharmaceutical firms have a significantly higher proportion of R&D expenditure to total assets.

Panel B of Table 7 for the time interval (*t*-1, *t*+1) analysis demonstrates that high-tech firms significantly decrease their adjusted patent citations after the Biopharmaceutical Act. In this short time interval, the DID estimators of the adjusted patent citations are significantly positive, implying that the approved biopharmaceutical firms have significantly higher innovation output than high-tech firms after the Biopharmaceutical Act. However, the DID estimator results for time interval (*t*-2, *t*+2) and (*t*-3, *t*+3) are not significant. Therefore, the results show that the effect of the Biopharmaceutical Act on the innovation quality of the biopharmaceutical industry is less significant, and has only a short duration. This result of a short run effect is consistent with David et al. (2000).

4.4.2 Difference-in-differences Regression (DID Regression)

Table 8 shows the DID regression results for the inter-industry analysis. In Panel A, the significantly negative coefficients of *Treatment* show that the approved

biopharmaceutical firms have lower R&D investment than the high-tech firms. In addition, the significantly positive coefficients of the interaction term, *After*×*Treatment*, show that compared with high-tech firms, approved biopharmaceutical firms increase R&D investment significantly after the Biopharmaceutical Act. Thus, these findings demonstrate that compared with high-tech firms, approved biopharmaceutical firms are more encouraged to increase R&D investment by the act.

Table 8 DID Regression Results: Inter-industry Analysis

Panel A: DID Regression Results for R&D Investment: Inter-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-1.4188	-1.3626	-2.1960***	-2.0770***	-0.6735	-0.4862	-0.0277	-0.0959
	(0.1807)	(0.1992)	(0.0045)	(0.0072)	(0.2655)	(0.4217)	(0.9633)	(0.8731)
$Treatment_i$	-3.1875***	-3.4854***	-3.3959***	-3.8954***	-1.9565***	-2.7109***	-1.8821***	-2.9477***
	(0.0005)	(0.0003)	(0.0000)	(0.0000)	(0.0059)	(0.0003)	(0.0093)	(0.0001)
$After_t \times Treatment_i$	3.1546**	3.1323**	3.6625***	3.5871***	2.3407**	2.2497**	1.9755**	1.9896**
	(0.0152)	(0.0159)	(0.0011)	(0.0014)	(0.0177)	(0.0223)	(0.0398)	(0.0376)
$LN\ (TA)_t$	-1.3558***	-1.3851***	-1.3597***	-1.3622***	-0.7284***	-0.7405***	-0.6099***	-0.6238***
	(0.0002)	(0.0001)	(0.0000)	(0.0000)	(0.0007)	(0.0006)	(0.0012)	(0.0009)
RD_{t-1}	0.4578***	0.4547***	0.5330***	0.5273***	0.5851***	0.5758***	0.6133***	0.5999***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.2356***	-0.2389***	-0.1988***	-0.2055***	-0.1721***	-0.1812***	-0.1725***	-0.1841***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$Debt\ Ratio_t$		-0.0132		-0.0257**		-0.0361***		-0.0481***
		(0.2954)		(0.0148)		(0.0000)		(0.0000)
Observations	1,489	1,489	2,334	2,334	3,256	3,255	4,154	4,153
Adjusted R^2	0.4900	0.4901	0.5243	0.5253	0.5226	0.5250	0.5496	0.5538

Panel B: DID Regression Results for Adjusted Patent Citations: Inter-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0617**	-0.0618**	-0.0734***	-0.0724***	-0.0439*	-0.0409	-0.0342*	-0.0315
	(0.0165)	(0.0189)	(0.0052)	(0.0057)	(0.0756)	(0.1002)	(0.0967)	(0.0507)

Table 8 DID Regression Results: Inter-industry Analysis (cont.)

Panel B: DID Regression Results for Adjusted Patent Citations: Inter-industry Analysis

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$Treatment_i$	-0.0602**	-0.0624**	-0.0846***	-0.0892***	-0.0943***	-0.0986***	-0.0797***	-0.0825***
	(0.0113)	(0.0140)	(0.0039)	(0.0041)	(0.0026)	(0.0034)	(0.0056)	(0.0076)
$After_t \times Treatment_i$	0.0693**	0.0730**	0.0829**	0.0817**	0.0675*	0.0646	0.0591	0.0511
	(0.0212)	(0.0218)	(0.0236)	(0.0316)	(0.0842)	(0.1166)	(0.1024)	(0.1807)
LN $(1+NetSales_{t-1})$	0.0041	0.0040	0.0050	0.0049	0.0092***	0.0096***	0.0084***	0.0089***
	(0.1087)	(0.1484)	(0.1215)	(0.1498)	(0.0057)	(0.0067)	(0.0043)	(0.0042)
RD_{t-1}	0.0019***	0.0019***	0.0036***	0.0035***	0.0052***	0.0052***	0.0048***	0.0047***
	(0.0001)	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Tobin's Q_{t-1}		-0.0008		0.0022		0.0034		0.0050*
		(0.6933)		(0.3806)		(0.2308)		(0.0567)
Observations	1,037	996	1,643	1,571	2,205	2,102	2,807	2,687
Adjusted R^2	0.0552	0.0563	0.0641	0.0678	0.0853	0.0889	0.0807	0.0845

Note: This table presents the panel regression results of the inter-industry analysis, including the regression of R&D investment and adjusted citations with one, two, three and four matching control firms. The dependent variable of Panel B is the natural logarithm of 1+adjusted patent citation, i.e. LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in the treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms and control firms are high-tech firms. The definitions of the variables are presented in Appendix Table A1. Numbers in parentheses are *p*-values.***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panel B of Table 8 shows significantly negative coefficients for Treatment, indicating that the approved biopharmaceutical firms have lower adjusted patent citations than the high-tech firms. In this panel, the coefficients of interaction term, *After*×*Treatment*, are positive significantly for one and two matched firms and are not significant for three and four matched firms. These results imply that approved biopharmaceutical firms are motivated more than high-tech firm to improve their innovation quality by the Biopharmaceutical Act, but the results are less significant.

In sum, both results of DID estimator and DID regression show that relative to high-

tech firms, the approved biopharmaceutical firms are more encouraged to invest in R&D activities and to improve their adjusted patent citations.[29] These findings show the policy effectiveness of the Biopharmaceutical Act is only for biopharmaceutical firms (rather than firms in other high R&D intensity industries) on innovation improvement.

4.4.3 Subsample Analysis of Inter-industry

The subsection considers two inter-industry subsample analyses. First, we consider the possible effect of firm size and divide the sample into small and large firms for the subsample analysis of inter-industry because the firm sizes of biopharmaceutical firms are smaller than those of high-tech industries in Table 1. In addition, small firms usually lack collaterals and are hard to obtain external financing for R&D (David et al., 2000; Hall, 2002). Further, small firms also find it more difficult to appropriate the returns from R&D and thus have less motivation to invest in R&D (Chen et al., 2013). Therefore, small firms are more likely to have serious R&D underinvestment problems.

Table 9 shows the subsample DID regression result of inter-industry. Panels A.1 and A.2 of Table 9 exhibit significantly positive coefficients for the interaction term, *After*×*Treatment*, showing that for firms of similar sizes, approved biopharmaceutical firms have significantly higher R&D investment after the Biopharmaceutical Act than high-tech firms. However, the coefficients of the interaction term in the small firms are larger than those of large firms. These findings show that in the inter-industry analysis, the effect of the Biopharmaceutical Act on innovation investment may be stronger for small firms than for large ones. Small firms with more serious underinvestment problems may be stimulated to increase R&D investment after the Biopharmaceutical Act because the tax credits help to alleviate the financing constraint problem in small firms. These results are consistent with the concept of Baghana and Mohnen (2009) and Lokshin and Mohnen (2012), who argue that tax credit policy tends to be more effective in stimulating R&D input for small firms than for large firms.

29 The stimulation of innovation quality in the inter-industry comparison is less significant than the innovation investment.

Table 9 DID Regression Result of Inter-industry: Subsample Analysis for Different Firm Size

Panel A.1 DID Regression Results for R&D Investment in the Inter-industry Analysis: Small Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-2.6563	-2.6443	-3.5811***	-3.4917***	-3.1244***	-2.9833***	-2.5278***	-2.3399***
	(0.6559)	(0.1597)	(0.0059)	(0.0074)	(0.0030)	(0.0046)	(0.0053)	(0.0098)
$Treatment_i$	-2.5368	-2.6266	-3.0630**	-3.3108**	-2.5942*	-3.0755**	-1.1068	-1.7929
	(0.1623)	(0.1552)	(0.0458)	(0.0328)	(0.0681)	(0.0324)	(0.4134)	(0.1898)
$After_t \times Treatment_i$	5.7595**	5.7399**	5.6477***	5.4853***	3.9550**	3.7895**	2.2866	2.1258
	(0.0188)	(0.0194)	(0.0053)	(0.0068)	(0.0308)	(0.0384)	(0.1806)	(0.2123)
$LN\ (TA)_t$	-2.6272***	-2.6131***	-1.7853***	-1.7428***	-1.4603***	-1.4334***	-0.6776**	-0.6314**
	(0.0002)	(0.0002)	(0.0008)	(0.0010)	(0.0006)	(0.0008)	(0.0242)	(0.0355)
RD_{t-1}	0.4280***	0.4268***	0.4836***	0.4794***	0.5712***	0.5634***	0.6058***	0.5950***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.2912***	-0.2936***	-0.2408***	-0.2471***	-0.1954***	-0.2055***	-0.1787***	-0.1923***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Debt $Ratio_t$		-0.0047		-0.0152		-0.0251**		-0.0322***
		(0.7906)		(0.2800)		(0.0299)		(0.0016)
Observations	671	671	1,072	1,072	1,483	1,483	1,865	1,865
Adjusted R^2	0.4839	0.4832	0.4832	0.4833	0.5288	0.5300	0.5355	0.5377

Panel A.2 DID Regression Results for R&D Investment in the Inter-industry Analysis: Large Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.4008	-0.6233	-0.3073	-0.3891	-0.6343	-0.7051	0.1333	0.0782
	(0.6559)	(0.4819)	(0.6832)	(0.6025)	(0.2851)	(0.2302)	(0.7997)	(0.8808)
$Treatment_i$	-2.6529***	-2.5552***	-3.0679***	-3.0077***	-2.5046***	-2.4400***	-2.3140***	-2.2546***
	(0.0006)	(0.0007)	(0.0001)	(0.0001)	(0.0002)	(0.0003)	(0.0005)	(0.0006)
$After_t \times Treatment_i$	2.5006**	2.8499***	2.6654**	2.8517***	2.6098***	2.7881***	2.2241**	2.3671***
	(0.0201)	(0.0073)	(0.0118)	(0.0067)	(0.0058)	(0.0030)	(0.0162)	(0.0099)
$LN\ (TA)_t$	-1.1017***	-1.0102***	-1.0538***	-0.9993***	-1.0786***	-1.0165***	-0.9345***	-0.8857***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Table 9 DID Regression Result of Inter-industry: Subsample Analysis for Different Firm Size (cont.)

Panel A.2 DID Regression Results for R&D Investment in the Inter-industry Analysis: Large Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
RD_{t-1}	0.4383***	0.4387***	0.5237***	0.5250***	0.5836***	0.5852***	0.6254***	0.6267***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.1489***	-0.1511***	-0.1579***	-0.1590***	-0.1052***	-0.1061***	-0.1117***	-0.1124***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Debt $Ratio_t$		0.0012***		0.0012***		0.0012***		0.0012***
		(0.0000)		(0.0000)		(0.0000)		(0.0000)
Observations	834	834	1,312	1,312	1,768	1,768	2,225	2,225
Adjusted R^2	0.5347	0.5493	0.5435	0.5509	0.5522	0.5609	0.5746	0.5813

Panel B.1 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: Small Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	0.0054	0.0122	-0.0291	-0.0263	-0.0109	-0.0090	0.0692**	0.0716**
	(0.8621)	(0.7011)	(0.3005)	(0.3623)	(0.6943)	(0.7514)	(0.0237)	(0.0507)
$Treatment_i$	0.0264	0.0391	-0.0351	-0.0307	-0.0311	-0.0294	0.0647	0.0705
	(0.3675)	(0.2263)	(0.2923)	(0.4067)	(0.4123)	(0.4848)	(0.1531)	(0.1642)
$After_t \times Treatment_i$	-0.0404	-0.0490	0.0311	0.0189	0.0236	0.0150	-0.0437	-0.0488
	(0.2573)	(0.2090)	(0.4247)	(0.6613)	(0.5912)	(0.7573)	(0.4096)	(0.4067)
LN $(1+NetSales_{t-1})$	0.0052*	0.0055*	0.0083**	0.0089**	0.0125***	0.0126***	0.0304***	0.0316***
	(0.0780)	(0.0831)	(0.0168)	(0.0180)	(0.0016)	(0.0030)	(0.0000)	(0.0000)
RD_{t-1}	0.0016***	0.0017***	0.0026***	0.0026***	0.0024***	0.0024***	0.0021***	0.0021***
	(0.0008)	(0.0010)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0002)
Tobin's Q_{t-1}		-0.0018		0.0050		0.0040		0.0018
		(0.6086)		(0.2172)		(0.3623)		(0.7291)
Observations	496	467	798	755	1,097	1,040	1,370	1,302
Adjusted R^2	0.0424	0.0424	0.1229	0.1275	0.1087	0.1144	0.1062	0.1094

Table 9 DID Regression Result of Inter-industry: Subsample Analysis for Different Firm Size (cont.)

Panel B.2 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: Large Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0592	-0.0542	-0.1010	-0.1033	-0.0849	-0.0884	-0.1498*	-0.1533*
	(0.6612)	(0.6919)	(0.3273)	(0.3221)	(0.2875)	(0.2743)	(0.0530)	(0.0507)
$Treatment_i$	-0.2198*	-0.1860	-0.1631	-0.1454	-0.0863	-0.0653	-0.0774	-0.0557
	(0.0604)	(0.1275)	(0.1182)	(0.1840)	(0.3429)	(0.4957)	(0.4300)	(0.5890)
$After_t \times Treatment_i$	0.2257	0.2121	0.2477*	0.2510*	0.2144*	0.2166*	0.2586*	0.2550*
	(0.1509)	(0.1921)	(0.0794)	(0.0873)	(0.0850)	(0.0948)	(0.0539)	(0.0685)
LN (1+$NetSales_{t-1}$)	0.0815***	0.0842***	0.0907***	0.0916***	0.0841***	0.0859***	0.0985***	0.0999***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RD_{t-1}	0.0088**	0.0094**	0.0111***	0.0114***	0.0108***	0.0111***	0.0113***	0.0113***
	(0.0378)	(0.0469)	(0.0002)	(0.0003)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Tobin's Q_{t-1}		-0.0028		-0.0051		-0.0049		-0.0036
		(0.7623)		(0.5588)		(0.5331)		(0.6696)
Observations	545	536	840	824	1,132	1,107	1,433	1,402
Adjusted R^2	0.1652	0.1639	0.1470	0.1470	0.1307	0.1318	0.1370	0.1377

Note: This table presents the panel regression results of subsamples divided by different firm sizes, including small and large firms in the inter-industry analysis. Panels A.1 and A.2 show the regression results that explain the R&D investment for small and large firms, respectively. Panels B.1 and B.2 show the regression results that explain the adjusted patent citations for these two subsamples. The dependent variable in Panels B.1 and B.2 is LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in that treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms and control firms are high-tech firms. The definitions of the variables are presented in Appendix Table A1. Numbers in parentheses are *p*-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Panels B.1 and B.2 of Table 9 present the inter-industry subsample analysis of adjusted patent citations. There are insignificant coefficients of the interaction term for the small firms but marginally significant coefficients of the interaction term for the large firms. These results show that only in the large firm group, approved biopharmaceutical

firms are more motivated to improve their innovation quality by the Biopharmaceutical Act than high-tech firms.

Next, we divide the sample into low and high R&D intensity firms because the previous section shows that the Biopharmaceutical Act encourages biopharmaceutical firms with low R&D intensity to invest more in innovation. This additional inter-industry subsample analysis explores whether the Biopharmaceutical Act also has a consistent effect in encouraging low R&D intensity firms in the biopharmaceutical industry rather than the high-tech industry.

The coefficients of the interaction term, *After*×*Treatment*, are significantly positive in Panel A.1 of Table 10 but not significant in Panel A.2 of Table 10. These results show that among low R&D intensity firms, the approved biopharmaceutical firms are more encouraged to increase innovation investments by the Biopharmaceutical Act than high-tech firms. In addition, for the high R&D intensity group, after the Biopharmaceutical Act, the approved biopharmaceutical firms do not have significantly different R&D intensity than the high-tech firms. This finding, which shows that the approved biopharmaceutical firms are motivated more to increase R&D investment by the Biopharmaceutical Act than high-tech firms, is driven primarily by the group of low R&D intensity firms. Further, in both Panel B.1 and B.2 of Table 10, the insignificant coefficients of interaction term, *After*×*Treatment*, show that the Biopharmaceutical Act does not result in any difference in the innovation quality between the approved biopharmaceutical firms and high-tech firms in either the low or the high R&D intensity firm groups. This finding shows that for both low and high R&D intensity firms, the Biopharmaceutical Act does not lead to any difference in the innovation quality between the approved biopharmaceutical firms and high-tech firms.

Table 10 DID Regression Result of Inter-industry: Subsample Analysis for Different R&D Intensity Level

Panel A.1 DID Regression Results for R&D Investment in the Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	1.7445	2.2429*	0.5603	0.7918	0.6222	0.7712	1.1356**	1.2328***
	(0.1440)	(0.0557)	(0.4719)	(0.3054)	(0.2847)	(0.1834)	(0.0165)	(0.0094)

Table 10 DID Regression Result of Inter-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel A.1 DID Regression Results for R&D Investment in the Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$Treatment_i$	-0.689	1.9281*	-0.3714	1.2276	0.4937	1.5582**	0.6711	1.2455*
	(0.5063)	(0.0839)	(0.6438)	(0.1542)	(0.4709)	(0.0326)	(0.2802)	(0.0589)
$After_t \times Treatment_i$	3.0262**	2.3428*	3.6293***	3.3018***	3.0472***	2.8048***	2.3919***	2.2496***
	(0.0351)	(0.0964)	(0.0010)	(0.0025)	(0.0011)	(0.0025)	(0.0042)	(0.0071)
$LN\ (TA)_t$	-0.4707	-0.4486	-0.7691***	-0.8312***	-0.5744***	-0.6115***	-0.5526***	-0.5702***
	(0.2082)	(0.2203)	(0.0036)	(0.0015)	(0.0043)	(0.0023)	(0.0008)	(0.0006)
RD_{t-1}	0.2557***	0.2704***	0.3018***	0.3137***	0.3344***	0.3439***	0.3853***	0.3913***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ROA_t	-0.2801***	-0.2495***	-0.1872***	-0.1680***	-0.1345***	-0.1221***	-0.1077***	-0.1001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
$Debt\ Ratio_t$		0.0817***		0.0517***		0.0344***		0.0179***
		(0.0000)		(0.0000)		(0.0001)		(0.0099)
Observations	720	720	1,094	1,094	1,482	1,482	1,857	1,857
Adjusted R^2	0.3521	0.3798	0.307	0.3211	0.2875	0.2952	0.2857	0.2879

Panel A.2 DID Regression Results for R&D Investment in the Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.8044	-0.1764	-2.6868**	-2.0907	-1.7973	-1.4135	-0.7549	-0.2784
	(0.6610)	(0.0557)	(0.0470)	(0.1209)	(0.1074)	(0.2012)	(0.4485)	(0.7778)
$Treatment_i$	-6.1900***	-6.8924***	-7.0898***	-8.1367***	-4.4423***	-5.9052***	-4.3913***	-5.8374***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0005)	(0.0000)	(0.0005)	(0.0000)
$After_t \times Treatment_i$	2.2862	1.478	4.3563**	3.4420*	3.4653**	2.7279	2.5106	1.6675
	(0.2885)	(0.4975)	(0.0209)	(0.0673)	(0.0474)	(0.1154)	(0.1454)	(0.3288)
$LN\ (TA)_t$	-1.2869**	-1.2031*	-1.3909***	-1.4913***	-1.1939***	-1.2449***	-0.6463**	-0.7218**
	(0.0367)	(0.0505)	(0.0020)	(0.0009)	(0.0006)	(0.0003)	(0.0451)	(0.0237)
RD_{t-1}	0.3676***	0.3654***	0.4727***	0.4645***	0.5548***	0.5391***	0.5476***	0.5320***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Table 10 DID Regression Result of Inter-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel A.2 DID Regression Results for R&D Investment in the Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
ROA_t	-0.3316***	-0.3457***	-0.2965***	-0.3131***	-0.2274***	-0.2510***	-0.2445***	-0.2682***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Debt $Ratio_t$		-0.0522**		-0.0781***		-0.0850***		-0.0904***
		(0.0288)		(0.0000)		(0.0000)		(0.0000)
Observations	690	690	1,124	1,124	1,538	1,538	1,968	1,968
Adjusted R2	0.4856	0.4885	0.5706	0.5775	0.5543	0.5639	0.5345	0.5455

Panel B.1 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: Low R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	-0.0156	-0.0149	0.0173	0.0175	0.0174	0.0173	0.0137	0.0136
	(0.5316)	(0.9097)	(0.3891)	(0.3987)	(0.2954)	(0.3129)	(0.2983)	(0.3144)
$Treatment_i$	-0.004	-0.0058	0.0001	-0.0001	-0.0009	-0.0013	-0.0030	-0.0016
	(0.8549)	(0.8106)	(0.9966)	(0.9972)	(0.9660)	(0.9537)	(0.8691)	(0.9364)
$After_t \times Treatment_i$	0.0386	0.0384	-0.0056	-0.0043	-0.0030	-0.0010	-0.0042	-0.0024
	(0.2095)	(0.2447)	(0.8509)	(0.8918)	(0.9131)	(0.9726)	(0.8652)	(0.9269)
LN $(1+NetSales_{t-1})$	0.0047*	0.0047	0.0040	0.0038	0.0034	0.0028	0.0003	-0.0004
	(0.0813)	(0.1193)	(0.1419)	(0.2163)	(0.1944)	(0.3300)	(0.8787)	(0.8551)
RD_{t-1}	0.0005	0.0004	0.0015*	0.0014	0.0012	0.0011	0.0008	0.0008
	(0.5052)	(0.6346)	(0.0732)	(0.1043)	(0.1440)	(0.2048)	(0.2234)	(0.2922)
Tobin's Q_{t-1}		0.0012		-0.0007		-0.0013		-0.0023
		(0.7205)		(0.8421)		(0.6979)		(0.4156)
Observations	632	592	968	922	1,320	1,261	1,658	1,589
Adjusted R^2	0.0245	0.0246	0.0155	0.0139	0.0213	0.0206	0.0166	0.0166

Table 10 DID Regression Result of Inter-industry: Subsample Analysis for Different R&D Intensity Level (cont.)

Panel B.2 DID Regression Results for Adjusted Patent Citations in the Inter-industry Analysis: High R&D Intensity Firms

	One Matched Firm		Two Matched Firms		Three Matched Firms		Four Matched Firms	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
$After_t$	0.0038	0.0054	-0.0954*	-0.0915*	-0.046	-0.0401	-0.1004**	-0.0932**
	(0.9344)	(0.9097)	(0.0711)	(0.0811)	(0.2955)	(0.3613)	(0.0114)	(0.0183)
$Treatment_i$	-0.0734*	-0.0779*	-0.1178*	-0.1163*	0.0115	0.0152	-0.0373	-0.0338
	(0.0787)	(0.0878)	(0.0528)	(0.0685)	(0.8424)	(0.8069)	(0.5114)	(0.5745)
$After_t \times Treatment_i$	0.0187	0.0196	0.0979	0.0698	0.0350	-0.0030	0.0873	0.0378
	(0.7497)	(0.7517)	(0.2290)	(0.4027)	(0.6501)	(0.9706)	(0.2593)	(0.6360)
LN (1+$NetSales_{t-1}$)	0.0076*	0.0074	0.0195***	0.0196***	0.0358***	0.0361***	0.0322***	0.0328***
	(0.0876)	(0.1341)	(0.0021)	(0.0038)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
RD_{t-1}	0.0015**	0.0013**	0.0006	0.0003	0.0008	0.0005	0.0016**	0.0013*
	(0.0156)	(0.0486)	(0.4083)	(0.6658)	(0.2572)	(0.5157)	(0.0135)	(0.0524)
Tobin's Q_{t-1}		0.0002		0.0081*		0.0102**		0.0142***
		(0.9483)		(0.0696)		(0.0216)		(0.0015)
Observations	598	558	986	929	1,368	1,290	1,754	1,663
Adjusted R^2	0.0638	0.0696	0.0729	0.081	0.1151	0.1256	0.0884	0.0984

Note: This table presents the panel regression results of subsamples divided by different firm sizes, including small and large firms in the inter-industry analysis. Panels A.1 and A.2 show the regression results that explain the R&D investment for low and high R&D intensity firms, respectively. Panels B.1 and B.2 show the regression results that explain the adjusted patent citations for these two subsamples. The dependent variable in Panels B.1 and B.2 is LN (1+adjusted patent citation). The regression is shown in equation (1) of Section 3.3.4. $After_t$ = 1 if the firm is in the approval year or after approval year and 0 otherwise; $Treatment_i$ = 1 if the firm is in the treated group and 0 otherwise. The treated firms are approved biopharmaceutical firms and control firms are high-tech firms. The definitions of the variables are presented in Appendix Table A1. Numbers in the parentheses are p-values. ***,**, and * denote significance at the 1%, 5%, and 10% levels, respectively.

5. Conclusion

This study investigates the impact of the Biopharmaceutical Act on firm innovation. To overcome the endogeneity problem, we first use the PSM approach to identify suitable control firms and then adopt the DID approach to examine how the innovation activities of approved biopharmaceutical firms, relative to control firms, respond to the exogenous

shock of the Biopharmaceutical Act. To demonstrate the benefits and policy effectiveness of the Biopharmaceutical Act, we conduct both intra-industry and inter-industry analyses.

The results of the intra-industry analysis show that the Biopharmaceutical Act induces the approved biopharmaceutical firms to increase innovation investments. This finding is consistent with most previous studies which find a positive effect of tax credits on R&D. The stimulation effect of the Biopharmaceutical Act on the innovation investments in the biopharmaceutical industry only exists among pharmaceutical and low R&D intensity firms. The subsample findings may have the similar economic implication since Yang et al. (2012) find that pharmaceutical firms usually have low R&D intensity. Pharmaceutical firms tend to underinvest more in R&D than non-pharmaceutical firms because of the high risk and fewer successful cases in new medicine, the long period required for innovation, and the substantial investment necessary. Low R&D intensity firms are more likely to underinvest in R&D. Therefore, these findings for pharmaceutical and low R&D intensity firms demonstrate the effectiveness of the Biopharmaceutical Act for firms with more serious underinvestment in R&D.

In addition, the inter-industry analysis supports the policy effectiveness of the Biopharmaceutical Act. The approved biopharmaceutical firms are motivated more to invest innovation and to improve innovation quality than high-tech firms. By investigating the SUI of Taiwan, Yang et al. (2012) find that the tax credits have more effect on R&D for industries with greater R&D intensity and suggest that the government should establish various tax credits. Therefore, our results support the argument of Yang et al. (2012) and confirm the effectiveness of the Biopharmaceutical Act, which grants the additional benefit of tax credits only for biopharmaceutical firms, while the SUI grants all industries the same preferential tax treatment.

Further, the results of the inter-industry analysis are dominated by low R&D intensity firms and small firms. These groups are more likely to suffer severe R&D underinvestment problems. Small firms often find it more difficult to appropriate the private returns of R&D and lack the physical assets to serve as collateral (David et al., 2000; Hall, 2002). These subsample results strengthen our finding that the policy effectiveness of Biopharmaceutical Act is greater for firms with more serious R&D underinvestment problems. This finding is also consistent with the contention of Baghana and Mohnen (2009) and Lokshin and Mohnen (2012) that tax credit policy tends to be more effective in stimulating the R&D investment for small firms than large firms.

Based on prior literature, if the government wants to have a stronger effect on R&D,

it should adopt tax credits rather than direct subsidies. In fact, the Biopharmaceutical Act primarily uses tax credits, which appears to be a good decision. After the empirical examination, we confirm the policy effectiveness of the Biopharmaceutical Act, especially for biopharmaceutical firms with more serious R&D underinvestment problems. In addition, studies show that the stimulating effect of tax credits is more rapid than that of direct subsidies (David et al., 2000). Our finding of a short run effect for the Biopharmaceutical Act confirms this result.

In conclusion, our empirical findings of the promoting effect of the Biopharmaceutical Act on innovation activities, support the theories regarding private R&D underinvestment. This Act offers tax credits for R&D investment and holding shares of biopharmaceutical firms, and grants tax credits to the top executives and technology investors for new shares in biopharmaceutical firms. The tax credit regulations reduce the cost of R&D investment and increases equity financing opportunities. Thus, the increasing innovation activities resulting from tax credit regulations support the financial constraint theory in explaining the problem of R&D underinvestment.

In addition, the Biopharmaceutical Act offers non-tax credit preferential treatments to reduce the agency problem (i.e. it stimulates managers' motivation) and to increase the incoming spillover effect by increasing cooperation opportunities. These non-tax credit treatments tend to support the agency theory and spillover theory in explaining R&D underinvestment. In this paper, discriminating between the tax credits and non-tax credits in exploring the stimulus effect of the Biopharmaceutical Act enables us to determine which theory better explains the R&D underinvestment. However, we do not obtain detailed information about the deduction of tax payment and the collaboration information between industries and academic institutions, and thus could not directly examine this interesting topic.

References

Aerts, K., and Schmidt, T. 2008. Two for the price of one?: Additionality effects of R&D subsidies: A comparison between Flanders and Germany. *Research Policy*, 37 (5): 806-822.

Aghion, P., and Howitt, P. 1992. A model of growth through creative destruction. *Econometrica*, 60 (2): 323-351.

Aghion, P., Van Reenen, J., and Zingales, L. 2013. Innovation and institutional ownership. *The American Economic Review*, 103 (1): 277-304.

Arrow, K. 1962. Economic welfare and the allocation of resources for invention. In Universities-National Bureau Committee for Economic Research, Committee on Economic Growth of the Social Science Research Council (Ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*: 609-626. Princeton, NJ: Princeton University Press.

Artz, K. W., Norman, P. M., Hatfield, D. E., and Cardinal, L. B. 2010. A longitudinal study of the impact of R&D, patents, and product innovation on firm performance. *Journal of Product Innovation Management*, 27 (5): 725-740.

Baghana, R., and Mohnen, P. 2009. Effectiveness of R&D tax incentives in small and large enterprises in Québec. *Small Business Economics*, 33 (1): 91-107.

Becker, B. 2015. Public R&D policies and private R&D investment: A survey of the empirical evidence. *Journal of Economic Surveys*, 29 (5): 917-942.

Becker-Blease, J. R. 2011. Governance and innovation. *Journal of Corporate Finance*, 17 (4): 947-958.

Bena, J., and Li, K. 2014. Corporate innovations and mergers and acquisitions. *The Journal of Finance*, 69 (5): 1923-1960.

Bessen, J., Neuhäusler, P., Turner, J. L., and Williams, J. 2014. The costs and benefits of United States patents. *SSRN Electronic Journal*. doi: 10.2139/ssrn.2278255

Bhattacharya, M., and Bloch, H. 2004. Determinants of innovation. *Small Business Economics*, 22 (2): 155-162.

Blundell, R., and Costa-Dias, M. 2009. Alternative approaches to evaluation in empirical microeconomics. *Journal of Human Resources*, 44 (3): 565-640.

Brown, J. R., Fazzari, S. M., and Petersen, B. C. 2009. Financing innovation and growth: Cash flow, external equity, and the 1990s R&D boom. *The Journal of Finance*, 64 (1): 151-185.

Brown, J. R., Martinsson, G., and Petersen, B. C. 2012. Do financing constraints matter for R&D?. *European Economic Review*, 56 (8): 1512-1529.

_____. 2017. What promotes R&D? Comparative evidence from around the world. *Research Policy*, 46 (2): 447-462.

Buckley, J., and Shang, Y. 2002. Estimating policy and program effects with observational data: The "differences-in-differences" estimator. *Practical Assessment, Research, and Evaluation*: Vol. 8, Article 24.

Bushee, B. J. 1998. The influence of institutional investors on myopic R&D investment behavior. *The Accounting Review*, 73 (3): 305-333.

Caliendo, M., and Kopeinig, S. 2008. Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, 22 (1): 31-72.

Carboni, O. A. 2011. R&D subsidies and private R&D expenditures: Evidence from Italian manufacturing data. *International Review of Applied Economics*, 25 (4): 419-439.

Cerulli, G., and Potì, B. 2012. Evaluating the robustness of the effect of public subsidies on firms' R&D: An application to Italy. *Journal of Applied Economics*, 15 (2): 287-320.

Chan, L. K. C., Lakonishok, J., and Sougiannis, T. 2001. The stock market valuation of research and development expenditures. *The Journal of Finance*, 56 (6): 2431-2456.

Chang, H. Y., Liang, W. L., and Wang, Y. 2019. Do institutional investors still encourage patent-based innovation after the tech bubble period?. *Journal of Empirical Finance*, 51: 149-164.

Chang, X., Fu, K., Low, A., and Zhang, W. 2015. Non-executive employee stock options and corporate innovation. *Journal of Financial Economics*, 115 (1): 168-188.

Chen, H. C. 2013. *The impact of effective tax rate and R&D outlays on the implementation of biotech and new pharmaceutical development act of biotechnology pharmaceutical industries in Taiwan*. Unpublished master's thesis, Department of Accounting, Soochow University, Taipei, Taiwan.（陳欣喬，2013，*生技新藥產業發展條例對生藥產業有效稅率與研發支出影響之研究*，東吳大學會計學研究所未出版之碩士論文，臺北，臺灣。）

Chen, S. S., Chen, Y. S., Liang, W. L., and Wang, Y. 2013. R&D spillover effects and firm performance following R&D increases. *Journal of Financial and Quantitative Analysis*, 48 (5): 1607-1634.

_____. 2020. Public R&D spending and cross-sectional stock returns. *Research Policy*, 49 (1). doi: https://doi.org/10.1016/j.respol.2019.103887

Chen, Y. C. 2017. *The impact of national health insurance policy on Taiwan pharmaceutical company for launching domestic new drug*. Unpublished master's thesis, Graduate Institute of Technology, Innovation & Intellectual Property Management, National Chengchi University, Taipei, Taiwan.（陳怡君，*全民健保藥價政策對臺灣本土研發新藥上市策略的影響*，國立政治大學科技管理與智慧財產研究所未出版之碩士論文，臺北，臺灣。）

Cohen, W. M., Nelson, R. R., and Walsh, J. P. 2000. *Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not) (NBER Working Paper No. 7552)*. Cambridge, MA: National Bureau of Economic Research.

Connolly, R. A., and Hirschey, M. 2005. Firm size and the effect of R&D on Tobin's q. *R&D Management*, 35 (2): 217-223.

Czarnitzki, D., Hanel, P., and Rosa, J. M. 2011. Evaluating the impact of R&D tax credits on innovation: A microeconometric study on Canadian firms. *Research Policy*, 40 (2): 217-229.

Czarnitzki, D., and Hussinger, K. 2004. *The link between R&D subsidies, R&D spending and technological performance (ZEW-Centre for European Economic Research Discussion Paper No. 04-056)*. Mannheim, Germany: Leibniz Center for European Economic Research. doi: http://dx.doi.org/10.2139/ssrn.575362

David, P. A., Hall, B. H., and Toole, A. A. 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy*, 29 (4-5): 497-529.

Dehejia, R. H., and Wahba, S. 2002. Propensity score-matching methods for nonexperimental causal studies. *The Review of Economics and Statistics*, 84 (1): 151-161.

Duguet, E. 2004. Are R&D subsidies a substitute or a complement to privately funded R&D? An econometric analysis at the firm level. *Revue D'Economie Politique*, 114 (2): 245-274.

Eisner, R., Albert, S. H., and Sullivan, M. A. 1984. The new incremental tax credit for R&D: Incentive or disincentive?. *National Tax Journal*, 37 (2): 171-183.

Franzen, L. A., Rodgers, K. J., and Simin, T. T. 2007. Measuring distress risk: The effect of R&D intensity. *The Journal of Finance*, 62 (6): 2931-2967.

Greve, H. R. 2003. A behavioral theory of R&D expenditures and innovations: Evidence from shipbuilding. *Academy of Management Journal*, 46 (6): 685-702.

Griliches, Z. 1981. Market value, R&D, and patents. *Economics Letters*, 7 (2): 183-187.

_____. 1990. Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, 28 (4): 1661-1707.

Hægeland, T., and Møen, J. 2007. *The relationship between the Norwegian R&D tax credit scheme and other innovation policy instruments (Statistics Norway Reports 2007/47)*. Oslo, Norway: Statistics Norway's Information Centre.

Hall, B. H. 1993. R&D tax policy during the 1980s: Success or failure?. *Tax Policy and the Economy*, 7: 1-35.

_____. 2002. The financing of research and development. *Oxford Review of Economic Policy*, 18 (1): 35-51.

Hall, B. H., Jaffe, A. B., and Trajtenberg, M. 2001. *The NBER patent citation data file: Lessons, insights and methodological tools (NBER Working Papers No. 8498)*. Cambridge, MA: National Bureau of Economic Research.

_____. 2005. Market value and patent citations. *The RAND Journal of Economics*, 36 (1): 16-38.

Hall, B. H., and Van Reenen, J. 2000. How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy*, 29 (4-5): 449-469.

Heckman, J. J., Ichimura, H., and Todd, P. E. 1997. Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. *The Review of Economic Studies*, 64 (4): 605-654.

Hitt, M. A., Hoskisson, R. E., Ireland, R. D., and Harrison, J. S. 1991. Effects of acquisitions on R&D inputs and outputs. *Academy of Management Journal*, 34 (3): 693-706.

Hsu, P. H. 2009. Technological innovations and aggregate risk premiums. *Journal of Financial Economics*, 94 (2): 264-279.

Hsu, P. H., Tian, X., and Xu, Y. 2014. Financial development and innovation: Cross-country evidence. *Journal of Financial Economics*, 112 (1): 116-135.

Hsu, S. Y. 2018. *The effect of government policy to biopharmaceutical industry*. Unpublished master's thesis, Executive Master Business Administration, National Chengchi University, Taipei, Taiwan.（許淑燕，2018，*生技產業政策對生技製藥公司發展之影響*，國立政治大學經營管理碩士學程未出版之碩士論文，臺北，臺灣。）

Huang, C. J., and Chang, C. Y. 2020. The relationships among characteristics of interlocking directorate network, technological diversity and innovation performance: Evidence from Taiwan's electronics industry. *NTU Management Review*, 30 (3): 145-182.（黃政仁與張肇元，2020，董事連結網絡特性、技術多角化與創新績效之關聯性研究：以臺灣電子業為例，*臺大管理論叢*，30 卷 3 期：145-182。）

Huang, M. J. 2019. The relationship between board interlocks and corporate tax avoidance. *NTU Management Review*, 29 (2): 201-232.（黃美祝，2019，董事連結與企業避稅程度之關聯性，*臺大管理論叢*，29 卷 2 期：201-232。）

Jones, C. I., and Williams, J. C. 1998. Measuring the social return to R&D. *The Quarterly Journal of Economics*, 113 (4): 1119-1135.

Kao, M. J. 2012. *Analysis of bioindustry policy: Evidence from Taiwan public firms*. Unpublished master's thesis, Department of Economics, National Taiwan University, Taipei, Taiwan.（高曼蓉，2012，*生物技術產業政策分析：以臺灣公開發行之廠商為例*，國立臺灣大學經濟學研究所未出版之碩士論文，臺北，臺灣。）

Klassen, K. J., Pittman, J. A., Reed, M. P., and Fortin, S. 2004. A cross-national comparison of R&D expenditure decisions: Tax incentives and financial constraints. *Contemporary Accounting Research*, 21 (3): 639-680.

Klette, T. J., and Møen, J. 2012. R&D investment responses to R&D subsidies: A theoretical analysis and a microeconometric study. *World Review of Science, Technology and Sustainable Development*, 9 (2-4): 169-203.

Klette, T. J., Møen, J., and Griliches, Z. 2000. Do subsidies to commercial R&D reduce market failures? Microeconomitric evaluation studies. *Research Policy*, 29 (4-5): 471-495.

Kong, L. 2020. Government spending and corporate innovation. *Management Science*, 66 (4): 1584-1604.

Lach, S. 2002. Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. *The Journal of Industrial Economics*, 50 (4): 369-390.

Lane, W. R., Looney, S. W., and Wansley, J. W. 1986. An application of the cox proportional hazards model to bank failure. *Journal of Banking and Finance*, 10 (4): 511-531.

Lechner, M. 2011. The estimation of causal effects by difference-in-difference methods. *Foundations and Trends in Econometrics*, 4 (3): 165-224.

Lerner, J. 1994. The importance of patent scope: An empirical analysis. *The RAND Journal of Economics*, 25 (2): 319-333.

Li, D. 2011. Financial constraints, R&D investment, and stock returns. *The Review of Financial Studies*, 24 (9): 2974-3007.

Li, G. C., Lai, R., D'amour, A., Doolin, D. M., Sun, Y., Torvik, V. I., Yu, A. Z., and Fleming, L. 2014. Disambiguation and co-authorship networks of the U.S. patent inventor database (1975-2010). *Research Policy*, 43 (6): 941-955.

Lokshin, B., and Mohnen, P. 2012. How effective are level-based R&D tax credits? Evidence from the Netherlands. *Applied Economics*, 44 (12): 1527-1538.

Mansfield, E. 1986. The R&D tax credit and other technology policy issues. *The American Economic Review*, 76 (2): 190-194.

Ministry of Economic Affairs. 2018. *2018 Biotechnology Industry White Paper of Bureau of Industry*. Taipei, Taiwan: Industrial Development Bureau, Ministry of Economic Affairs.（經濟部工業局，2018，*2018 生技產業白皮書*，臺北，臺灣：經濟部工業局。）

Özçelik, E., and Taymaz, E. 2008. R&D support programs in developing countries: The Turkish experience. *Research Policy*, 37 (2): 258-275.

Porter, M. E. 1992. Capital disadvantage: America's failing capital investment system. *Harvard Business Review*, 70 (5): 65-82.

Romer, P. M. 1990. Endogenous technological change. *Journal of Political Economy*, 98 (5): S71-S102.

Rosenbaum P. R., and Rubin, D. B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70 (1): 41-55.

Shefer, D., and Frenkel, A. 2005. R&D, firm size and innovation: An empirical analysis. *Technovation*, 25 (1): 25-32.

Sun, J. C. L. 2003. Innovation strategies of Taiwan's biotechnology industry. *Review of Taiwan Economics*, 9 (2): 113-139.（孫智麗，2003，臺灣生技產業發展現況與產業創新策略，*經濟情勢及評論季刊*，9 卷 2 期：113-139。）

Taiwan Venture Capital Association. 2008. *2008 Taiwan Venture Capital Association Yearbook*. Taipei, Taiwan: Industrial Development Bureau, Ministry of Economic Affairs.（中華民國創業投資商業同業公會，2008，*2008 年臺灣創業投資年鑑*，臺北，臺灣：經濟部工業局。）

Takalo, T., and Tanayama, T. 2010. Adverse selection and financing of innovation: Is there a need for R&D subsidies?. *The Journal of Technology Transfer*, 35 (1): 16-41.

Tillinger, J. W. 1991. An analysis of the effectiveness of the research and experimentation tax credit in a q model of valuation. *Journal of the American Taxation Association*, 13 (2): 1-29.

Toivanen, O., and Niininen, P. 2000. *Investment, R&D, subsidies, and credit constraints (HSEBA Working Paper No. W-264)*. Helsinki, Finland: Department of Economics MIT and Helsinki School of Economics.

Trajtenberg, M. 1990. A penny for your quotes: Patent citations and the value of innovations. *The RAND Journal of Economics*, 21 (1): 172-187.

Wallsten, S. J. 2000. The effects of government-industry R&D programs on private R&D: The case of the small business innovation research program. *The RAND Journal of Economics*, 31 (1): 82-100.

Wernerfelt, B., and Montgomery, C. A. 1988. Tobin's *q* and the importance of focus in firm performance. *The American Economic Review*, 78 (1): 246-250.

Winston, C. 2006. *Government Failure versus Market Failure: Microeconomics Policy Research and Government Performance*. Washington, DC: AEI-Brookings Joint Center for Regulatory Studies.

Wong, C. H. 2007. Focus: Development of the biotechnology and pharmaceutical industry in Taiwan (The report on the monthly meeting of the presidential palace). *Taiwan Economic Forum*, 5 (8): 3-23.（翁啟惠，2007，政策焦點：生技製藥產業在台灣的發展（2007年7月總統府月會專題報告），*台灣經濟論衡*，5卷8期：3-23。）

Wu, Y. 2005. The effects of state R&D tax credits in simulating private R&D expenditure: A cross-state empirical analysis. *Journal of Policy Analysis and Management*, 24 (4): 785-802.

Yang, C. H., Huang, C. H., and Hou, T. C. T. 2012. Tax incentives and R&D activity: Firm-level evidence from Taiwan. *Research Policy*, 41 (9): 1578-1588.

Appendix Table A1 The Definitions of Variables

Variables	Definitions
Patent	The total number of patents applied for by a firm.
Adjuste'Citation	The patent citation is the total number of citations received from all granted patents that are filed by a firm. The adjusted citation is followed Hall, Jaffe, and Trajtenberg (2001, 2005) to adjust patent citation by correcting the number of citations received by each patent by the application year and technology classification. Specifically, Hall et al. (2001) classify the 3-digit IPC code into 6 main industrial categories and use the simulated cumulated lag distribution of each category to calculate the truncation adjusted citations.
R&D Expenditure	R&D expenditure (millions of New Taiwan Dollars)
R&D intensity	R&D expenditure divided by total assets (percentage)
Total Assets	Total assets (millions of New Taiwan Dollars)
Debt Ratio	Total liability divided by total assets (percentage)
Net Sales	Net sales (millions of New Taiwan Dollars)
ROA (Return On Asset)	Earnings before interest, taxes, depreciation, and amortization (EBITDA) divided by the average of total assets (percentage)
Tobin's Q	Market value of equity plus book value of long-term and short-term debts, divided by book assets

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