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R&D subsidies in permissive and restrictive environment: Evidence from Korea

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R&D Subsidies in Permissive and Restrictive Environment: Evidence from Korea

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Abstract

This paper investigates the extent to which a regulatory environment for R&D subsidies shapes the magnitude and direction of R&D subsidies set by a government and consequent innovation paths. When the WTO adopted a permissive regulatory environment, we find that the Korean government increased R&D subsidies significantly (89.21%) and selectively so for firms and industries with higher returns. Recipient firms conducted less basic research and more development research. Improvements in innovations were mostly incremental and minor. However, such changes did not persist once the WTO switched to a restrictive regulatory environment. Our findings show that the regulatory environment imposed by the WTO largely affects allocation of R&D subsidies and suggest that a permissive regulatory environment may not necessarily maximize the potential for breakthrough innovations.

Keywords: R&D subsidy, regulatory environment, WTO, innovations, patent, utility model.
JEL Classification Numbers: F13, H25, O32.

1 Introduction

Given the broad consensus that "innovation is the only way for the most developed countries to secure sustainable long-run productivity growth" (Bloom et al. 2019, p.163), governments actively subsidize firms' research and development (R&D) activities. Such policy intervention is justified based on the presence of market imperfections (Arrow 1962). That is, private R&D is likely to be under-supplied due to limited appropriability, high risk and uncertainty, external benefits to the production of knowledge, financing constraints, etc. (Martin and Scott 2000). Therefore, government subsidies can help firms to undertake R&D activities that are socially beneficial but too costly to conduct on their own.

With the prevalence of government subsidies and growing availability of micro-level data, many empirical works focused on *recipient firms* to assess changes brought by R&D subsidies. Main interests lie in analyzing whether recipient firms increased or displaced private investment upon receiving subsidies (Holger and Strobl 2007; Lach 2002; Marino et al. 2016; Szücs 2020; Wallsten 2000), or in quantifying program- or firm-specific returns to subsidies based on various outcome measures (Almus and Czarnitzki 2003; Audretsch et al. 2002; Bronzini and Iachini 2014; Bronzini and Piselli 2016; Einiö 2014; Howell 2017; Lerner 1999; Smith 2020). In comparison, other studies alternatively focused on a *government* to highlight R&D subsidy as its strategic policy object and linked this to productivity and growth in the long run (Aghion et al. 2015; Beason and Weinstein 1996; Bloom et al. 2019). Whereas the overall empirical literature on R&D subsidies is extensive and still growing, one common implication is that allocation of R&D subsidies by a government can have a large influence on R&D activities and innovation outcomes.

Yet, there is one critical factor that has been overlooked in the literature. Although a government determines R&D subsidies as its domestic policy, its policy space for subsidies is constrained by international regulations. Incorporating such regulatory constraint may not be essential when the focus of analysis is on subsidy recipients, but it becomes critical in analyzing a government's overall allocation of R&D subsidies. This is because such regulatory environment can shape R&D subsidization patterns and outcomes, as there are potential negative consequences for violating international regulations. Therefore, this paper aims to address this lacuna in the literature by placing R&D subsidization and its impact within an international regulatory context. By doing so, we can better assess underlying incentives of and consequences from R&D subsidization from a broader perspective.

We empirically examine the following questions in this paper. How does a regulatory environment for R&D subsidies shape the magnitude and direction of R&D subsidies set by a government? Does a permissive regulatory environment provide more favorable conditions for maximizing the potential for innovations?

In this paper, we capture the internationally agreed upon rules that determine the scope of a government's subsidy policies using the WTO's Agreement on Subsidies and Countervailing Measures (hereinafter the "SCM Agreement" or the "WTO subsidy rules"). While the SCM Agreement governs all types of subsidies in general, one interesting feature is that it had different transition phases for regulating R&D subsidies in particular. During the 1995-1999 period, the WTO adopted a *permissive* regulation by treating R&D subsidies as non-actionable ("green light") subsidies. In 2000, the WTO switched to a *restrictive* regulation by placing R&D subsidies in the category of actionable ("yellow light") subsidies. That is, R&D subsidies can be subject to challenge in the WTO or to countervailing measures if they target specific firms or industries and cause adverse effects to other countries. In essence, a government's policy space was larger during the 1995-1999 period as R&D subsidies intended to bring commercial advantages to specific firms or industries in their competition with foreign counterparts were also permitted. Hereinafter, we refer to the permissive (restrictive) regulatory environment as the "GL period" ("YL period").

Exploiting the exogenous transition phases for R&D subsidies, we analyze our research questions using data from the Republic of Korea (hereinafter Korea). Korea is one of the countries that invest most heavily in R&D.[1] Our main dataset is the annual government survey from the Report on the Survey of Research and Development, which contains information on R&D activities, subsidies, and private expenditures for a representative sample of firms in the manufacturing sector from 1991 to 2010. We further collect data on patent and utility model applications of domestic firms from the Korea Intellectual Property Rights Information Service. Our empirical analyses are based on the following research designs: event study approach, GMM method, and difference-in-differences

[1]In 2017, Korea had the largest R&D expenditure as a percentage share of GDP (4.55%) among the OECD countries (OECD 2019). It also had the fourth largest government support to business R&D as a percentage of GDP among the OECD countries in 2018 (OECD 2021).

(DID) method.

The empirical findings can be summarized as the following. First, the government increased R&D subsidies for firms significantly during the GL period (i.e. 89.21% increase than before based on the GMM estimates), but such increase did not persist in the YL period. Second, the increase in R&D subsidies during the GL period was particularly concentrated on large firms or firms in industries with greater returns in the past. The recipient firms conducted less basic research and more development research during the GL period. Taken together, these two findings imply that the government was "strategic" in its allocation of subsidies. It intensively and selectively subsidized firms to exploit the permissive regulatory environment. Lastly, we find that there was consequently a strong improvement in minor and incremental innovations (i.e. utility models), while improvements in fundamental innovations (i.e. patents) remained modest.

The main contribution of this paper is that it empirically analyzes the allocation of R&D subsidies made in response to an international regulatory environment and its consequent impact on innovation paths. The empirical context of this paper rests on Korea's R&D subsidy allocations in response to the WTO subsidy rules, but it has broader implications applicable to other international regulations (e.g. in the areas of environment, labor standards, intellectual property rights, etc.) and other countries. One of the critical factors determining outcomes of any international regulations is government policy adjustments. Our findings highlight that government policy adjustments can be made strategically at a country level, and such strategic policy responses should be applicable to any country in any regulatory context.[2] At the same time, we believe our empirical context itself is also interesting and important. Some may argue that R&D subsidies seem to be not much responsive to international regulations, given few dispute cases brought to the WTO regarding R&D subsidies in comparison to large R&D subsidy programs in place.[3] Yet, data on disputes and legal outcomes provide only an incomplete picture of consequences arising from imposing regulations. This is because they do not capture policy adjustments that governments make without causing disputes and legal rulings.[4]

[2]Strategic policy responses are commonly found in the literature regarding various international regulations or agreements such as food safety standards (Henson and Jaffee 2008), environmental standards (Barrett 1994; Ederington and Minier 2003), pollution emissions (Duan et al. 2021), labor standards (Bagwell and Staiger 2001; Brown et al. 1993), and intellectual property rights (Grossman and Lai 2004; Žigić 2000).

[3]These dispute cases are DS70, DS316, DS317, and DS353.

[4]The paucity of WTO rulings on certain rules does not mean that the rules are unimportant, as legal

Indeed, we find that the policy adjustments in R&D subsidies were quite significant in our empirical context.

This paper is also important from a policy perspective given the following implications. First, our study highlights the difficulty of balancing various goals in allocating R&D subsidies for a government, given various degrees of spillovers and expected returns arising at different points in time. The evidence from the GL period shows that the government exploited this period to intensively and selectively subsidize certain R&D activities and this mostly improved rather minor and incremental innovations. Such strategic tendency in subsidy allocation may be more pronounced in an environment where policymakers are under pressure to deliver quick and identifiable outcomes from allocating a tight budget. Given that R&D activities with high risk but large potential spillovers are especially likely to be under-supplied without government subsidization, our findings suggest that those R&D activities may still be under-supplied with the presence of strategic subsidization.

In addition, our findings have implications on designing regulatory environment for R&D subsidies. A permissive regulatory environment enables a government to freely allocate R&D subsidies in pursuit of its prioritized goals. In our empirical context, we find that the strategic allocation of subsidies had more impact on improving incremental innovations, as opposed to fundamental innovations. Thus, a permissive regulatory environment may not necessarily be more favorable in inducing breakthrough innovations. Perhaps regulations on R&D subsidies can better support innovations with large social returns if permissiveness or restrictiveness of regulations is designed to be research-type dependent.

2 Literature Review

Our paper is related to several strands of literature. First, there are works that focus on the role of legal frameworks that govern R&D activities and innovations. Barbosa and Faria (2011) provide an overview of various institutional regulations and their links to innovations. Effects of regulations on innovations are often found to be mixed. They can either hamper R&D activities by imposing rigid constraints and increasing compliance costs, or promote innovations by protecting intellectual property rights and addressing

rulings do not surface as equilibrium outcomes if governments adjust policies to avoid other members' complaints (Staiger and Sykes 2017).

inefficiencies in the market (Blind 2012). Therefore, previous literature has investigated R&D activities and innovations in various regulatory contexts. Some examples include environmental regulations (Palmer et al. 1995; Porter 1991; Porter and van der Linde 1995), intellectual property rights (Encaoua et al. 2006; Gallini 1992, 2002; Jaffe 2000; Moser 2005; Scotchmer 1991), labor laws (Acharya et al. 2013, 2014; Balsmeier 2017; Francis et al. 2018; Griffith and Macartney 2014), and product market regulations (Amable et al. 2016; Rzakhanov 2008; Sanyal and Ghosh 2013). Our paper adds to this broad literature, by focusing on R&D subsidies in a regulatory context and its consequent impact on innovations.

Our paper is also closely related to the literature highlighting heterogeneous outcomes arising from different types of R&D activities. Hottenrott et al. (2017) make a distinction between research and development and show that research grants trigger additional private R&D more effectively than development grants. Akcigit et al. (2021) build an R&D-driven growth model in which basic research brings spillovers to subsequent innovations *within* and *across* industries, whereas applied research generates innovations *within* a targeted industry. Without government intervention, Akcigit et al. (2021) find that there would be an overinvestment in applied research. These studies suggest that returns to subsidies vary across different types of R&D activities, and they do so when the government engages in selective subsidization to target certain outcomes. Yet, identifying such strategic incentives based on overall subsidization patterns in the data can be difficult. Our paper makes the use of variations in a regulatory environment to highlight the presence of strategic subsidies empirically.

Moreover, there are studies that distinguish different types of innovations based on degrees of novelty and importance. Radical innovations "embody a new technology that results in a new market structure" (Garcia and Calantone 2002, p.120) and consequently involve higher costs and risks (Schilling 2013). In contrast, incremental innovations "provide new features, benefits, or improvements to the existing technology in the existing market" (Garcia and Calantone 2002, p.123) and help firms to sustain or improve competence through small improvements (Beck et al. 2016). Although both radical and incremental innovations are essential for firms to enhance their competitiveness (Beck et al. 2016), their direction and impact are clearly different. For example, Kim et al. (2012) find that the relative importance of radical versus incremental innovations in a country changes depending on the level of economic and technological development. In line with these studies, our paper also distinguishes different degrees of innovation outcomes. Namely, we use data on patents and utility models to capture the outcomes of fundamental and minor innovations, respectively, driven by R&D subsidies.

Lastly, the WTO subsidy rules used in our empirical context have received much attention in trade or law literature (Bagwell and Staiger 2006; Howse 2020; Lee 2016; Mavroidis et al. 2008; Sykes 2005, 2010). Here, one of the main questions on the WTO subsidy rules has been how governments agree on the use of domestic policies beyond conventional tariff negotiations under the regulatory environment. The importance of this research agenda arises as the WTO includes more agreements to govern domestic policy instruments compared to the General Agreement on Tariffs and Trade (hereinafter GATT).[5] Against this backdrop, many theoretical works were developed but empirical analyses remained scarce due to difficulties in identification.[6] Our paper adds to this empirical literature on the WTO subsidy rules by exploiting specific rules on R&D subsidies for identification, since R&D subsidies were treated as an exception and restrictions were gradually tightened in multiple phases.[7]

3 Institutional Background

The SCM Agreement regulates *specific* subsidies, which are limited to certain enterprises or industries or groups of enterprises or industries. The SCM Agreement classifies specific subsidies into two basic categories: prohibited subsidies (i.e. "red light" subsidies) and actionable subsidies (i.e. "yellow light" subsidies). Specific subsidies are actionable (i.e. subject to challenge in the WTO or to countervailing measures) if they cause "adverse effects" to the interests of another member, which can be one of the followings: (i) injury to a domestic industry caused by subsidized imports, (ii) the nullification or impairment of the market access expected from a tariff commitment, and (iii) serious prejudice which arises from a loss of exports in the subsidizing-country or a third-country market.

[5]For example, besides the SCM Agreement, the WTO includes the agreements on Trade-Related Aspects of Intellectual Property and on Sanitary and Phytosanitary Measures.

[6]Lee (2016) offers a survey of the theoretical literature examining the WTO subsidy rules.

[7]More specifically, Article 8 in the SCM Agreement granted the GL status for the following three types of subsidies as an exception: (i) R&D subsidies for research activities conducted by firms or by higher education or research establishments on a contract basis with firms, (ii) regional support for disadvantaged regions within the territory of a WTO member, and (iii) environmental subsidies for easing firms' compliance with new environmental requirements in their existing facilities.

Aside from the two basic categories, the SCM Agreement contained another category of non-actionable subsidies (i.e. "green light" subsidies) defined in Article 8. One of the green light subsidies listed was "R&D subsidies for research activities conducted by firms or by higher education or research establishments on a contract basis with firms." However, the green light status was only guaranteed from 1995 to 1999, since its application was provisional. The SCM Agreement stipulated that the Committee shall review whether the green light status should be extended or modified before the end of this period. On December 20, 1999, a meeting was held to discuss the green light status but no consensus was reached.[8] As a result, the application of green light subsidies expired on January 1, 2000 and R&D subsidies have been classified as yellow light subsidies since then.

Based on the aforementioned changes, we divide the time frame into three periods: i) the pre-WTO period before 1995; ii) the GL period from 1995 to 1999; and iii) the YL period from 2000. During the pre-WTO period, the GATT was in place. Focusing on tariff reductions, the GATT was generally tolerant to the use of subsidies.[9] Compared to the GATT, the SCM Agreement strengthened regulations on subsidies with more explicit legal provisions. Yet, as for R&D subsidies, the GL period represents a *permissive* regulatory environment in which R&D subsidies intended to bring commercial advantages to specific firms or industries were also allowed even when those subsidies caused adverse effects to another member. In contrast, the YL period represents a more *restrictive* regulatory environment for R&D subsidies as those subsidies became actionable.

[8]Proponents for extending the green light status were Bulgaria, Canada, Colombia, Cyprus, Czech Republic, the European Community, Japan, Korea, Poland, Slovenia, Switzerland, Turkey, and the United States. Opponents were Argentina, Egypt, India, Indonesia, Malaysia, Mexico, Pakistan, Panama, and Thailand.

[9]Although the GATT attempted to reduce export subsidies, it permitted subsidies that do not disrupt the market access expected from tariff reductions, while allowing the use of countervailing measures when domestic industries are injured by subsidized imports (Sykes 2005). More specifically, the GATT provided countervailing measures and non-violation complaints by which a government could react to either (i) injury to a domestic industry caused by subsidized imports, or (ii) the nullification or impairment of the market access expected from tariff commitments.

4 Data

4.1 Overview

Our main data come from the following sources: 1) Report on the Survey of Research and Development and 2) Korea Intellectual Property Rights Information Service. The Report on the Survey of Research and Development is an annual survey conducted by the Korean government for policy making purposes. The data are publicly accessible online via the National Assembly Library website.[10] This is a self-reported survey using a representative sample of firms, research institutes, and universities. In our main analysis, we use the sample of firms in 16 industries in the manufacturing sector from 1991 to 2010. The list of the industries that we use is in Table A1 in the Appendices. The survey started back in 1963 and covers other industries besides the ones that we use. We focus on the 16 industries from 1991 to 2010 because this is the largest consistent sample that we can use, given that there were changes in the classification of industries in the data across years.

The variables that we use from the survey are R&D subsidies, private R&D spending, the amount of total R&D investment for each type of R&D activities (i.e. basic, applied, and development), and sales. Some may raise concerns on the reliability of the self-reported survey data. As an initial step, we check for any red flags by cross-checking the summation amounts of R&D expenditures based on different composition criteria (e.g. by source of funds, type of R&D, and type of usage). We do not find any inconsistencies. However, one data limitation is that the variables are reported at the industry-size class-year level. That is, individual firm-specific information is not available. Instead, for an industry in a year, similarly-sized firms are grouped together and the average value for that group of firms is reported. Firms are classified into four size groups based on the number of employees: fewer than 100 employees, 100 to 299 employees, 300 to 999 employees, and more than 1,000 employees. For example, for the group of firms with less than 100 employees in the textiles industry in 1995, we know the average value of R&D subsidies per firm. Although we do not have firm-specific information, there are still rich variations in the data across industries, size classes, and years.

As for innovation outcomes, we use a web scraping program to collect data on patents and utility models from the Korea Intellectual Property Rights Information Service.[11] Ac-

[10]Source: `https://www.nanet.go.kr/main.do`

[11]Source: `http://eng.kipris.or.kr/enghome/main.jsp`

cording to the World Intellectual Property Organization (WIPO), utility model systems "require compliance with less stringent requirements (for example, lower level of inventive step), have simpler procedures and offer shorter term of protection" compared to patents. The WIPO describes a utility model system as a protection for "minor inventions" or "technical inventions" that "make small improvements to, and adaptations of, existing products or that have a short commercial life."[12] Therefore, whereas both patents and utility models capture inventions, we measure relatively minor or incremental innovations using utility models and more fundamental or radical innovations using patents. From 1991 to 2010, we search for all patents and utility models which are i) related to one of the 16 industries that we use; and ii) are owned by domestic firms in Korea. To identify whether a patent/utility model is relevant to the industries that we analyze, we refer to its International Patent Classification (IPC) codes that represent a particular area of technology. Then we use the Korea Standard Industry Classification (KSIC) - IPC concordance table published by the Korean Intellectual Property Office to map patents/utility models to relevant industries.[13] As for the ownership, we clean the applicant names in the data and keep patents/utility models for which at least one domestic firm is included as an applicant. This gives us a total of 362,113 patent and 147,166 utility model applications during our sample period.

4.2 Summary Statistics

Table 1 shows the basic summary statistics during our sample period. During our sample period of 20 years, the average number of surveyed firms in a year equalled 6,310 in the data. The number of surveyed firms increased across years. For instance, there were 24,091 surveyed firms in 2010. All firms in the survey data were either affiliated with research institutes or had their own R&D divisions. In the next set of rows in Table 1, we now show the summary statistics at the size group-industry-year level. There are 4

[12]Source: `https://www.wipo.int/patents/en/topics/utility_models.html` Besides Korea, these countries also have a utility model system: Australia, Austria, China, Denmark, Finland, France, Germany, Greece, Italy, Japan, Spain, and Taiwan.

[13]The concordance table can be found here: `https://www.kipo.go.kr/kpo/HtmlApp?c=4031&catmenu=m06_07_05`. If a patent has multiple IPC codes listed, we use all of them to identify relevant industries. 92.22% of applications are uniquely matched to one of the 16 industries that we use. 7.22% of applications are matched to two industries. For the applications with multiple industries, we include them in the count for each of the relevant industries. We find that dropping patents/utility models with multiple matched industries does not change the robustness of our results.

Table 1: Summary Statistics

	Mean	Std Dev	No. of Obs
<Year level>			
Number of surveyed firms in a year	6,310.65	(4,893.68)	20
<Size group- industry - year level>			
R&D expenditure	8,021.07	(21,535.43)	1,209
% of R&D funds financed by gov. subsidies	8.46	(10.22)	1,209
% of R&D funds financed by private sector	91.36	(10.30)	1,209
% of R&D funds financed by foreign sector	0.16	(1.06)	1,209
% of basic research conducted	8.76	(8.07)	1,209
% of applied research conducted	18.76	(11.29)	1,209
% of development research conducted	72.47	(14.82)	1,209

Note: The unit of average R&D expenditure is real million Korean won, deflated by the CPI (base year 2010). We use observations from 1991 to 2010. Except for the sample size, the remaining variables are computed using per firm values within a size group in an industry in a year.

size groups in 16 industries across 20 years. However, we end up with 1,209 observations since there were no surveyed firms for some size group-industry-year categories in the survey data. The average R&D expenditure per firm for a given size group in an industry in a year equaled approximately 8,021.07 (unit: real million Korean won). However, as shown by a large standard deviation, the value ranges from 55.34 to 194,426.38 (unit: real million Korean won) in the data. Firms finance their R&D expenditure from their private source, foreign source, and government subsidies. R&D subsidies in our data are defined as direct monetary payments which exclude other indirect forms of subsidization, such as tax relief, loan guarantee, or price reductions. Throughout this paper, we will thus use the term R&D subsidies to capture direct monetary payment from the government. On average, government subsidies accounted for 8.46% of R&D expenditure. Yet, firms in smaller size groups show a higher reliance on subsidies– the average subsidized share equaled 14.45% for firms with fewer than 100 employees, compared to 4.68% for firms with more than 1,000 employees. Among different R&D activities, firms spent the most on development research. In Table A1 in the Appendices, we present a more detailed summary of statistics for each of the 16 industries separately.

In Figure 1, we plot the average amount of R&D subsidies received by an organization for research institutes, colleges/universities, and firms, respectively. In each panel, the first (second) dashed vertical line marks the end of the pre-WTO (GL) period. Whereas

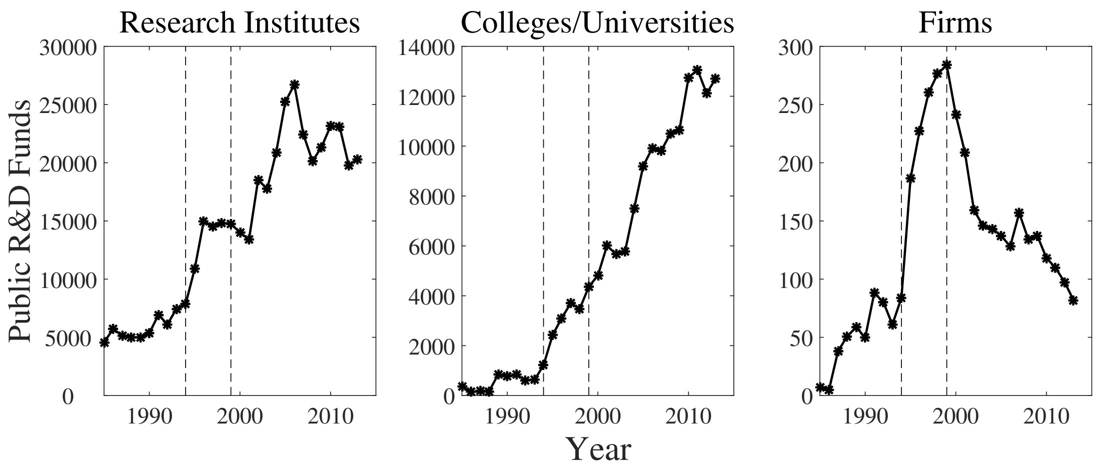


Figure 1: R&D Subsidies Across Different Organizations.

Notes: The figures show the average amount of R&D subsidies for each type of institution across years. The amounts are denoted in real million Korean won, deflated by the CPI (base year 2010). The first (second) dashed vertical line marks the end of the pre-WTO period (GL period).

the average R&D subsidies for research institutes and colleges/universities increased over time, the trend for firms is hump-shaped with a peak in 1999. The rapid increase from 1995 to 1999 coincides with the GL period and the falling trend since 2000 coincides with the YL period. Thus, we observe sharp changes in R&D subsidies for firms, which exactly coincide with the timing of the changes in the WTO subsidy rules. It is unlikely that the need for government intervention suddenly increased for firms only during 1995-1999 and then fell after 2000, but not for research institutes and colleges/universities. Thus, the sharp changes in R&D subsidies for firms seem to be driven by the changes in regulatory environment. Indeed, we find consistent pieces of evidence from press narratives and policy reports in Korea suggesting that the government should be cautious in its use of R&D subsidies for firms given the WTO subsidy rules.[14]

Nevertheless, we consider alternative explanations. One may question whether the increase in R&D subsidies during the GL period was perhaps driven by the replacement of falling private R&D investment due to the Asian Financial Crisis. In Figure 2, we show the trend of average R&D subsidies and average private R&D spending per firm. We focus on the period (1997-2001) during which Korea received a bailout package from

[14]See Ahn (2007), Cheung and Ahn (2011), and Park and Park (2007). An example of an opinion piece can be found in the Dong-a Ilbo newspaper on March 26th, 2010. (http://news.donga.com/3/all/20100326/27114693/1)

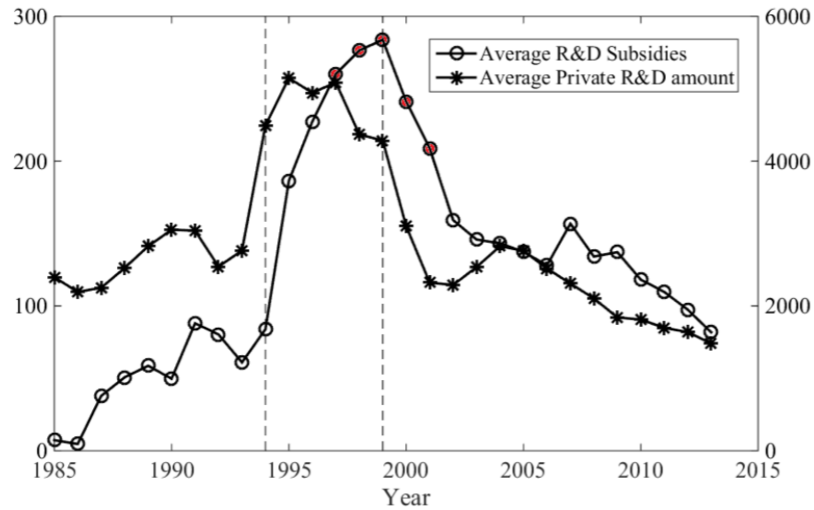


Figure 2: R&D Subsidies and Private R&D Funds for Firms

Notes: The label on the left (right) y-axis is for average R&D subsidies (average private R&D amount). The amounts are in real million Korean won, deflated by the CPI (base year 2010). The first (second) dashed vertical line marks the end of the pre-WTO period (GL period).

the International Monetary fund. With the beginning of the Asian Financial Crisis in 1997, the private R&D spending fell immediately. If the increase in government subsidies were to replace the falling private R&D spending, one would expect subsidies to increase continuously even after 1999 to make up for the falling private R&D. However, at the end of the GL period in 1999, R&D subsidies also fell sharply.[15] Therefore, it seems like replacement for private R&D spending cannot be the main underlying cause. Another possibility is that perhaps returns to innovations fell for some reason in the 2000s for firms only, and this led to a reduction in both private and public R&D spending. However, as we will later see in Figure 4, the number of patents owned by firms continually increased even after 1999, suggesting that the returns to innovations and R&D incentives remained high.

In sum, the graphical evidence shows that there were sharp changes in R&D subsidies for firms in line with the GL and YL periods. Subsidies for firms show different trends compared to subsidies for research institutes and colleges/universities, as well as private

[15]One may question whether responses from the government were delayed due to the stickiness of subsidy allocation. However, this is less likely to be the case since the Ministry of Economy and Finance in Korea announces budget plans for R&D subsidies each year and the allocation of funds is largely affected by current economic agenda or events.

R&D spending by firms. Therefore, we discuss empirical designs necessary to identify the causal impact of the regulatory environment on R&D subsidies and innovations in the next section.

5 Empirical Research Designs

The GL status for R&D subsidies was guaranteed from 1995 to 1999, but whether there would be an extension, modification, or termination afterwards was uncertain. This was particularly so since the WTO members had different opinions on extending the GL status (see footnote 8). Because no member had any unilateral power to determine the WTO subsidy rules, such regulation changes are plausibly exogenous from a country's perspective. It is also unlikely that Korea knew about the regulation changes in advance, or had influence that is substantially greater than other countries.

To analyze the impact of the WTO subsidy rules on R&D subsidies, we estimate the following:

$$y_{k,m,t} = \alpha_0 + \alpha_1 \mathbb{1}(\mathrm{GL})_t + \alpha_2 \mathbb{1}(\mathrm{YL})_t + \phi_t + \mu_k + \rho_m + \epsilon_{k,m,t}. \tag{1}$$

The subscripts k, m, and t are industry, size class, and year, respectively. For instance, one key dependent variable that we use is $log(R\&D\ subsidies)_{k,m,t}$. This captures the logarithm of average R&D subsidies per firm for a group of surveyed firms in industry k with size class m in year t. There are 16 industries (k), 4 size classes (m), and year t ranges from 1991 to 2010.

The binary indicators $\mathbb{1}(\mathrm{GL})_t$ and $\mathbb{1}(\mathrm{YL})_t$ capture the GL and YL periods, respectively, and the omitted category is the pre-WTO period. The parameters of interest are α_1 and α_2, which measure the extent of change in the outcome variable ($y_{k,m,t}$) during either the GL or YL period, compared to the pre-WTO period. The underlying identification assumption is that in the absence of the WTO subsidy rules, the outcome variable would have evolved at the same rate holding everything else constant. One potential threat to this identification assumption is that the implementation timing of the WTO subsidy rules may have coincided with other factors that influenced R&D subsidization. To alleviate such concerns, we include the following control variables in our estimation. ϕ_t includes the following time-related variables: 1) a linear year trend; 2) a fixed effect for the Asian Financial Crisis (1997-2001) during which Korea received a bailout package; and 3) fixed effects for the years when each president served his or her term, since R&D policies can vary by presidents. We do not include year dummies since they would cause multicollinearity with our variables of interest, $\mathbb{1}(\text{GL})_t$ and $\mathbb{1}(\text{YL})_t$. μ_k and ρ_m capture industry fixed effects and size-class fixed effects, respectively. $\epsilon_{k,m,t}$ is the idiosyncratic error term, which we cluster at the year level.

To ensure the validity of our findings, we further conduct various robustness checks and falsification tests. First, we similarly analyze firms' private R&D expenditures for a comparison. Unlike government subsidies, firms' private R&D spending is not subject to the WTO subsidy rules. Therefore, we analyze whether there were any sharp changes in private R&D spending with respect to the GL and YL periods as a falsification test. Although there may be a crowd-out or crowd-in relationship between private R&D spending and government's R&D subsidies, we expect such indirect effects to be limited.[16]

Next, we estimate a dynamic version of the model using the Generalized Method of Moments (GMM) method. To allow previous subsidies to affect current subsidies, we include a lagged dependent variable in our estimation. Whereas we tried including various number of lags in different specifications, we include one year lagged dependent variable in our analysis since the effect from further lags is statistically insignificant. Apart from incorporating such dynamics, the GMM method addresses the possible endogeneity of explanatory variables and bias from omitted variables. Thus, we obtain consistent and efficient estimators using the GMM method to further complement our findings from the event study approach. Given relatively a modest sample size, we create one instrument for each variable and lag distance, as opposed to creating an instrument for each time period, variable, and lag distance.[17] We report robust standard errors and relevant test statistics to provide supporting evidence for our specifications.

Lastly, we estimate the DID model specification. Unlike the event-study approach, which only relies on the time-series variations, the DID approach compares the changes in the outcome for the treated group to that for the control group before and after the change

[16]Whether there is additionality (i.e. the crowding-in effect) or substitution (i.e. the crowding-out effect) between public R&D subsidies and private R&D investment is one of the key questions raised in the literature. See David et al. (2000) and Zuniga-Vicente et al. (2014) for an overview of empirical findings and Dimos and Pugh (2016) for a meta-regression analysis.

[17]This is to address the fact that a bias can arise and the validity of the Hansen test may become weak when too many instruments are used (Roodman 2009a).

in the regulatory environment. However, one main challenge in our context is identifying a suitable control group, given that the WTO subsidy rules were applied simultaneously to all firms.[18] Therefore, we consider research institutes as a control group since their R&D activities are also subsidized by the government. Although research institutes and firms are different types of organizations, research institutes can nevertheless serve as a meaningful and perhaps the best possible control group in this context. We discuss more on how we implement the DID approach and report our findings in Appendices A.2. We find that our DID results are also consistent with our findings from other empirical methods.

6 Results

In Section 6.1, we analyze the impact of the GL and YL periods on the magnitude of R&D subsidies. Then in Section 6.2, we analyze whether there were any significant changes in the direction of subsidization and R&D activities during the GL and YL periods. Lastly, in Section 6.3, we track consequent innovation outcomes.

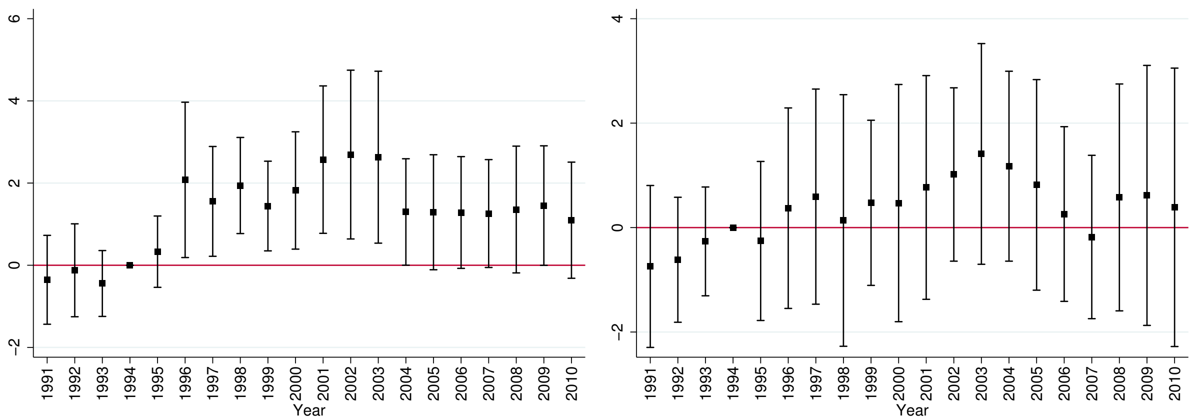
6.1 Magnitude of R&D Subsidies

First, we begin by examining R&D subsidies for each of the years before and after the adoption of the WTO subsidy rules using data on both firms and research institutes.

$$(2) \qquad y_{k,e,t} \;=\; \alpha + \sum_{\substack{k=-4 \\ k\neq -1}}^{15} \beta_k \cdot \mathbb{1}(e = \text{Firm}) \cdot \mathbb{1}(t = 1995 + k) + \phi_t + \mu_k + \rho_e + \epsilon_{k,e,t}.$$

Subscripts k, e, and t are industry, entity type (i.e. firm or research institute), and year, respectively. For example, the dependent variable of $log(\text{R\&D subsidies})_{k,e,t}$ captures logarithm of average R&D subsidies per organization given entity type e, industry k, and year t. α is a constant term, ϕ_t captures year fixed effects, μ_k captures industry fixed effects, and ρ_e is the entity type fixed effect. $\epsilon_{k,e,t}$ is an idiosyncratic error term. The

[18] The application of the rules was not conditional upon any features, such as exporting or importing firms, industries, amount of R&D subsidies, or any other characteristics. This is because any R&D subsidies to firms can be challenged if they are specifically targeted and cause adverse effects to another member.



(a) R&D Subsidies

(b) Private R&D Spendings

Figure 3: Year-specific Coefficient Trajectories.

Notes: The points represent the estimated effects of event time (i.e. the β_k's from equation (2)), with bars representing the 95% confidence intervals. The dependent variable is log(R&D subsidies) in panel (a) and log(private R&D spending) in panel (b). One year before the GL period (i.e. year 1994) is the omitted category.

coefficients of interest are the β_k's on time indicators for firms. Year 1994 is omitted so that the post-treatment effects are relative to one year before the adoption of the WTO subsidy rules. By looking at the β_k's, our goal is to examine whether there were any sharp changes in the outcome of interest around when the subsidy rules changed.

Using $log(\text{R\&D subsidies})_{k,e,t}$ as the dependent variable, we plot the values of estimated β_k's and their 95% confidence intervals in Figure 3a. First, all coefficients for the pre-WTO period are insignificantly different from zero, providing evidence for the parallel trend assumption before the treatment. Note that this evidence is necessary for identification of the DID analysis in Section A.2. Once the GL period begins, the coefficients become positive and statistically different from zero. During the YL period, the coefficients eventually diminish in their levels, although they remain slightly positive. Therefore, we observe meaningful changes in R&D subsidies in line with the regulation periods. In Figure 3b, we similarly estimate the same regression using $log(\text{private R\&D})_{k,e,t}$ as the dependent variable. Since private R&D spending is not subject to the WTO subsidy rules, we expect to see little or no impact around the GL and YL periods. Indeed, we find that the estimated β_k's for private R&D spending are insignificantly different from zero throughout, regardless of different periods. That is, once we control for year fixed effects, industry fixed effects, and entity type fixed effects, we do not find evidence that private R&D spending for firms changed significantly during the GL or YL periods, compared to that for research institutes.[19]

Table 2: Impact of the GL and YL Periods on the Magnitude of R&D Spending

Dep. variable:	$\log(\text{R\&D subsidies})_{k,m,t}$			$\log(\text{Private R\&D})_{k,m,t}$		
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}(\text{GL})_t$	1.2695***	0.8403**	0.7296*	0.0663	-0.0635	-0.062
	(0.2796)	(0.3501)	(0.3749)	(0.1137)	(0.1298)	(0.1310)
$\mathbb{1}(\text{YL})_t$	1.1079***	0.3398	0.3378	-0.0276	-0.1524	-0.1524
	(0.2721)	(0.4645)	(0.4156)	(0.1479)	(0.1442)	(0.1444)
Observations	1,209	1,209	1,209	1,209	1,209	1,209
R-squared	0.532	0.535	0.536	0.853	0.855	0.855
$\mathbb{1}(\text{GL})_t = \mathbb{1}(\text{YL})_t$	0.3704	0.0174	0.0227	0.1584	0.0297	0.0263
Linear time trend	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Size-class FE	Yes	Yes	Yes	Yes	Yes	Yes
President FE		Yes	Yes		Yes	Yes
Asian financial crisis			Yes			Yes

Notes: The estimation is conducted at the industry–size class–year level using data on firms. There are 4 size groups in 16 industries across 20 years. However, we have 1,209 observations as opposed to 1,280, since there were no surveyed firms for some size group-industry-year and such observations are dropped due to missing data in the survey. Asterisks ***/**/* denote p<0.01, p<0.05, p<0.1, respectively. The amounts are in real million Korean won, deflated by the CPI (base year 2010). Standard errors are clustered at the year level.

Using data on firms, we now present the results from estimating equation (1) in Table 2. In columns (1) to (3), the dependent variable is logarithm of average R&D subsidies per firm, for a group of surveyed firms in industry k with size class m in year t. We find that there was a statistically significant increase in R&D subsidies during the GL period across all specifications, compared to the pre-WTO period. Our most preferred specification in column (3), which accounts for a linear time trend, industry fixed effects, size-class fixed effects, president fixed effects, and an indicator for Asian financial crisis, shows an increase of 107.43% in R&D subsidies during the GL period than before. As for

[19] One may wonder how the result in Figure 3b can be reconciled with the trend shown in Figure 2. Figure 2 suggests that the overall average *level* of private R&D spending per firm fell since 1997. However, Figure 3b shows that once we net out various year-specific, industry-specific, and entity-specific unobservable fixed effects, private R&D spending by firms does not show any statistically significant changes *in comparison* to private R&D spending by research institutes.

the impact of the YL period, the positive effect is only statistically significant in column (1). The magnitude of coefficient for $\mathbb{1}(\text{YL})_t$ is always smaller than that for $\mathbb{1}(\text{GL})_t$ across all specifications. Still, one may question why the average level of R&D subsidies during the YL period did not reduce significantly given stricter rules. Although R&D subsidies became actionable in 2000, not all R&D subsidies are challenged in reality. To soften the shock of policy changes, the government may have selectively reduced R&D subsidies that were at a higher risk of being challenged during the YL period. We further test whether the coefficients of $\mathbb{1}(\text{GL})_t$ and $\mathbb{1}(\text{YL})_t$ are statistically different. We can reject the equality hypothesis at 5% level in columns (2) and (3).

In columns (4) to (6), we further analyze private R&D spending for a comparison. We find that the impact of both $\mathbb{1}(\text{GL})_t$ and $\mathbb{1}(\text{YL})_t$ are statistically insignificant across all specifications. That is, we do not find any meaningful changes in private R&D spending across different periods marked by the WTO subsidy rules. Overall, our estimates from the event study approach are consistent with the evidence in Figure 3.

In Table 3, we supplement our findings by estimating a dynamic panel model via GMM following Roodman (2009b). The specification is analogous to the one used in our event study approach, but we now include lagged dependent variable and exclude time-invariant fixed effects. This new specification allows R&D subsidies and private R&D spending to be affected by their previous values. Consistent with our findings in Table 2, the GMM estimates show a statistically significant increase in R&D subsidies during the GL period (i.e. 89.21% to 96.99%) compared to the pre-WTO period. Although the coefficient for the YL period is positive, it is statistically insignificant in columns (1) and (2) and we can reject the equality hypothesis for the coefficients of GL and YL at 5%. As for private R&D spending, columns (3) and (4) show that there are no meaningful responses with respect to the GL and YL periods.

Despite controlling for an extensive set of unobservable features, one may still argue that the changes in R&D subsidies may have been driven by other factors that varied contemporaneously with the timing of the GL period. In Appendices A.2, we thus implement the DID method using research institutes as the control group. Using the sample of firms and research institutes during the pre-WTO and GL periods, we still find a statistically significant treatment effect (i.e. the GL period) in our DID analysis.

Table 3: Impact of the GL and YL Periods on the Magnitude of R&D Spending—GMM

Dep. variable:	$\log(\text{R\&D subsidies})_{k,m,t}$		$\log(\text{Private R\&D})_{k,m,t}$	
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{GL})_t$	0.6780***	0.6377**	-0.0586	-0.0634
	(0.2548)	(0.2623)	(0.0865)	(0.0830)
$\mathbb{1}(\text{YL})_t$	0.2467	0.1884	-0.1354	-0.1640
	(0.3509)	(0.3615)	(0.1128)	(0.1110)
$\log(\text{R\&D subsidies})_{k,m,t-1}$	0.2568***	0.2445***		-0.0330*
	(0.0700)	(0.0724)		(0.0172)
$\log(\text{Private R\&D})_{k,m,t-1}$		0.1375	0.3076***	0.3177***
		(0.2723)	(0.0850)	(0.0695)
Observations	1,128	1,128	1,128	1,128
$\mathbb{1}(\text{GL})_t = \mathbb{1}(\text{YL})_t$	0.0323	0.0260	0.3258	0.1780
P-value for AR(2)	0.783	0.755	0.940	0.740
P-value for Hansen Test	0.449	0.354	0.335	0.627
DF for Hansen Test	5	4	5	4
Linear time trend	Yes	Yes	Yes	Yes
President FE	Yes	Yes	Yes	Yes
Asian financial crisis	Yes	Yes	Yes	Yes

Notes: The estimation is conducted at the industry–size class–year level using data on firms. The number of observations is 1,128, after accounting for missing data and including lagged variables in the regression. Asterisks ***/**/* denote $p<0.01$, $p<0.05$, $p<0.1$, respectively. The amounts are in real million Korean won, deflated by the CPI (base year 2010). We use the second and third lags of log(R&D subsidies) and log(Private R&D) as instruments. Robust standard errors are reported.

6.2 Directions of Subsidization and R&D Activities

We investigate whether firms' R&D activities and the direction of subsidization changed in response to the subsidy rules. In the WTO's dispute cases, subsidies seem to be perceived differently depending on the types of R&D activities conducted. One of the contentious issues is whether R&D activities were aimed at disseminating basic, broad knowledge as opposed to seeking immediate commercial benefits. For example, in a meeting with the Panel to resolve disputes with the European Communities (DS353) regarding R&D subsidies granted to The Boeing Company, the U.S. argued:

> "...For both the R&D purchases and provision of goods and services, we would also like to point out that NASA focuses on basic, fundamental R&D covering a broad range of aeronautics topics. It does not fund the development

> of particular products, or promote the interests of particular companies. It disseminates the resulting knowledge to the broadest possible extent. Thus, it conveys no commercial advantage."[20]

Ideally, we would like to analyze whether the government increased subsidies during the GL period which would otherwise be regulated during the YL period. However, such sensitive information is not identified in the data. Instead, we make use of the information on the types of R&D activities that firms conducted across different periods. Note that the survey data report the shares of *total* R&D expenditure spent on basic, applied, or development research, respectively. The data do not report how much of R&D subsidies were spent on each type of R&D activity. However, even if R&D subsidies were earmarked to a certain type of R&D activity, what ultimately matters is how intensively firms conducted each type of R&D activity. This is because even with earmarked subsidies, firms can readily change the overall composition of their R&D activity using their private R&D spending. Thus, fungibility of R&D funds implies that it does not matter whether a dollar spent on basic research is funded by the government or by the firm itself.

In Table 4, we analyze whether firms' tendency to conduct a particular type of R&D activity depends on the extent to which they rely on government subsidies, and especially so during the GL period. The dependent variable is the average share of total R&D expenditure spent on basic research (development research) per firm for a group of surveyed firms in industry k with size-class m in year t in the first (latter) two columns. The rest of the explanatory variables are the same as in Table 3, except for the term named Subsidized share$_{k,m,t-1}$. This variable measures the average share of R&D expenditure that was subsidized by the government per firm in year $t-1$ for industry k with size-class m. Columns (1) and (3) have the same specifications, except for the dependent variable. Column (1) shows that the coefficient for Subsidized share$_{k,m,t-1}$ $\times \mathbb{1}(\text{GL})_t$ is negative and statistically significant at 1%, whereas column (3) shows that the coefficient is positive and statistically significant at 5%. This suggests that the tendency to reduce (increase) basic research (development research) share upon having a higher reliance on government subsidies was particularly more evident during the GL period than before. Whereas such

[20]This quote comes from the Oral Statement of the United States at the first substantive meeting of the Panel with the parties, September 26, 2007. Source: `https://ustr.gov/archive/assets/Trade_Agreements/Monitoring_Enforcement/Dispute_Settlement/WTO/Dispute_Settlement_Listings/asset_upload_file475_13177.pdf`

Table 4: Subsidized Shares and Types of R&D Activities Conducted

	(1)	(2)	(3)	(4)
Dependent variable:	Basic $\text{share}_{k,m,t}$		Dev. $\text{share}_{k,m,t}$	
Subsidized $\text{share}_{k,m,t-1} \times \mathbb{1}(\text{GL})_t$	-0.1961***	-0.5972**	0.2341**	0.8603
	(0.0437)	(0.2630)	(0.1085)	(0.7931)
Subsidized $\text{share}_{k,m,t-1} \times \mathbb{1}(\text{YL})_t$	-0.1743***	-0.3986**	0.1918	0.6142
	(0.0375)	(0.1833)	(0.1155)	(0.6425)
Subsidized $\text{share}_{k,m,t-1}$	0.0866***	0.3672**	0.026	-0.4107
	(0.0202)	(0.1792)	(0.0906)	(0.6007)
$\mathbb{1}(\text{GL})_t$	0.0156	0.0377	-0.0093	-0.0554
	(0.0116)	(0.0227)	(0.0077)	(0.0409)
$\mathbb{1}(\text{YL})_t$	0.0353**	0.0369**	-0.0197	-0.0415
	(0.0155)	(0.0175)	(0.0213)	(0.0345)
Observations	1,128	1,128	1,128	1,128
Method	OLS	GMM	OLS	GMM
R-squared	0.112		0.147	
P-value for AR(2)		0.932		0.593
P-value for Hansen test		0.544		0.228
DF for Hansen test		8		8

Note: The estimation is conducted at the industry–size class–year level using data on firms. The number of observations ends up to be 1,128, after accounting for missing data and including lagged variables in the regression. Asterisks ***/**/* denote $p<0.01$, $p<0.05$, $p<0.1$ respectively. Robust standard errors are clustered at the year level in columns (1) and (3). Across all specifications, we include a linear time trend, president fixed effects, and the Asian Financial Crisis indicator. In columns (1) and (3), we further include industry fixed effects and size-class fixed effects. In column (2), we also include Basic $\text{share}_{k,m,t-1}$ and use second and third lags Basic share and Subsidized share as instruments. In column (4), we also include Dev. $\text{share}_{k,m,t-1}$ and use second and third lags of Dev. share and Subsidized share as instruments.

tendency is also present during the YL period, the absolute magnitude of impact is smaller than that during the GL period. In columns (2) and (4), we estimate a dynamic version of the model using GMM, which includes one year lagged dependent variable. The GMM estimates also show consistent findings, although results are not statistically significant at standard levels in column (4). Overall, Table 4 shows that the tendency to conduct less basic research and more development research was particularly stronger during the GL period for firms that relied more heavily on government subsidies.

Next, we conduct a subgroup analysis to see whether the government favored certain types of industries or firms in its subsidization during the GL period. For each of the 16 industries, we compute the average values for the following criteria using the pre-WTO

Table 5: Heterogeneous Effects: A Subgroup Analysis

Dep. variable:	log(R&D subsidies)$_{k,m,t}$							
Criteria:	Sales/Subsidy		Patents/Subsidy		UM/Subsidy		Firm Size	
	Low	High	Low	High	Low	High	Small	Large
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}(GL)_t$	0.5018	0.9975***	0.4440	1.0459**	0.4293	1.0542**	0.7804	0.6115**
	(0.5618)	(0.2293)	(0.3680)	(0.3809)	(0.3965)	(0.3773)	(0.5244)	(0.2650)
$\mathbb{1}(YL)_t$	-0.0200	0.7408**	-0.1481	0.8814*	0.1615	0.5502	0.7606	-0.1281
	(0.6511)	(0.3528)	(0.4195)	(0.4477)	(0.4769)	(0.4302)	(0.5765)	(0.3183)
Observations	618	591	622	587	602	607	623	586
R-squared	0.538	0.510	0.500	0.539	0.510	0.539	0.499	0.660
Linear time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Size-class FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
President FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Asian financial crisis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The estimation is conducted at the industry–size class–year level using data on firms. Asterisks ***/**/* denote p<0.01, p<0.05, p<0.1, respectively. The amounts are in real million Korean won, deflated by the CPI (base year 2010). Standard errors are clustered at the year level. To create subsamples in columns (1) to (6), we first calculate the average values at the industry level using the pre-WTO period sample for each given criteria. Then using the median value, we divide the samples into two subgroups based on their industry level characteristics. The sample size is not exactly even across two subgroups given that we apply the median cutoff calculated at the industry level and there are some missing observations at the industry–size class–year level. Yet, note that the total number of observations across any two subgroups always equals 1,209. Column (7) contains firms with less than 300 employees and column (8) contains the rest of firms.

period data at the industry level: sales per subsidy, number of patents per subsidy, and number of utility models per subsidy. Then for each criteria, we use the median value to divide our sample into two groups based on their industry characteristics. In Appendices A.3, we report the categorization of industries. For instance, column (1) (column (2)) contains firms that belong in industries which had low (high) sales per subsidy during the pre-WTO period. A comparison of columns (1) and (2) shows that the increase in R&D subsidies during the GL period was much larger and significant for firms in the industries which had higher sales per subsidy during the pre-WTO period. Similarly, in columns (3) to (6), we also find that during the GL period, more subsidies were given to the firms in industries which had better patent (utility model) outcomes per subsidy during the pre-WTO period. In columns (7) and (8), we now alternatively divide the sample based on firm size. Column (7) (column (8)) contains the sample of firms with less (more) than 300 employees. We find that for the sample of larger firms in column (8), there was a statistically significant 84.32% increase in R&D subsidies during the GL period than before, while no statistically significant change was found for the sample of smaller firms in column (7). Altogether, Table 5 shows that the direction of subsidization was quite strategic in the sense that more subsidies were selectively granted to firms/industries that generated greater outputs per subsidy in the past.

6.3 Innovation Outcomes

To analyze innovation outcomes, we follow the literature and use "intermediate outputs of the innovation effort, such as the number of patents" (Carlino and Kerr 2015). More specifically, we use the count of patents and utility models owned by domestic firms. There are two things to note. First, one may question whether patents and utility models are created in response to the WTO subsidy rules given that innovation outcomes take time to be realized. To minimize a potential time lag, we focus on applications rather than final approved outcomes. Throughout this paper, we refer to patent (utility model) applications as patents (utility models) for short. Another issue is whether the decision of when to submit an application is affected by the WTO subsidy rules. Firms are more likely to submit applications when more R&D subsidies are available, since the government constantly tracks performance of firms that apply for or have received R&D subsidies for evaluation purposes.

Table 6: Impact on Patents and Utility Models

Dep. variable	$\mathbb{1}(Patent)_{k,t}$	$\mathbb{1}(UM)_{k,t}$	$log(Patents)_{k,t}$	$log(UM)_{k,t}$
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{GL})_t$	-0.2145	0.3515**	0.3078***	0.6058**
	(0.1280)	(0.1370)	(0.0630)	(0.2190)
$\mathbb{1}(\text{YL})_t$	-0.0189	0.8485***	0.4383***	1.1426***
	(0.2950)	(0.2490)	(0.0875)	(0.3440)
log(R&D subsidies)$_{k,t-1}$	-0.0050	-0.0743*	0.0531*	0.1648***
	(0.0396)	(0.0376)	(0.0271)	(0.0508)
log(Private R&D)$_{k,t-1}$	0.0934	0.0664	0.0348	0.1550
	(0.0562)	(0.0792)	(0.0780)	(0.1030)
Observations	303	303	303	303
R-squared	0.124	0.216	0.962	0.887
Linear time trend	Yes	Yes	Yes	Yes
President FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Asian Financial Crisis	Yes	Yes	Yes	Yes

Notes: The estimation is conducted at the industry–year level using patents and utility model applications submitted by domestic firms. There are 16 industries across 20 years, but the total number of observations is 303 since information on R&D subsidies and private R&D spending are missing for some observations at the industry–year level in the survey data. Asterisks ***/**/* denote p<0.01, p<0.05, p<0.1, respectively. Standard errors are clustered at the year level. In column (1), $\mathbb{1}(Patent)_t = 1$ if $\text{Patent}_{k,t} > \text{Patent}_{k,t-1}$ and 0 otherwise. Similarly, in column (2), $\mathbb{1}(UM)_t = 1$ if $\text{UM}_{k,t} > \text{UM}_{k,t-1}$ and 0 otherwise.

Table 6 presents the estimation at the industry-year level.[21] In column (1) of Table 6, the dependent variable $\mathbb{1}(Patent)_{k,t}$ is a binary variable that equals 1 if the number of patents in industry k in year t exceeds its value in the previous year, and 0 otherwise. Based on this binary measure, we do not find evidence that the subsidy rules affected the probability of patent increase. In column (2), however, we find that the probability of utility model increase is positive and statistically significant in both GL and YL periods, after accounting for a linear time trend and various unobservable fixed effects. The effect during the YL period is larger than that during the GL period, which may potentially be capturing lags in producing innovation outcomes.

In columns (3) and (4), we use the actual count of patents and utility models. We find

[21] We are unable to conduct our analysis at the industry-size class-year level, since the information on size class of firms is not available in the database for patents and utility models. Given that we conduct our analysis at a more aggregated level, the number of observations becomes smaller.

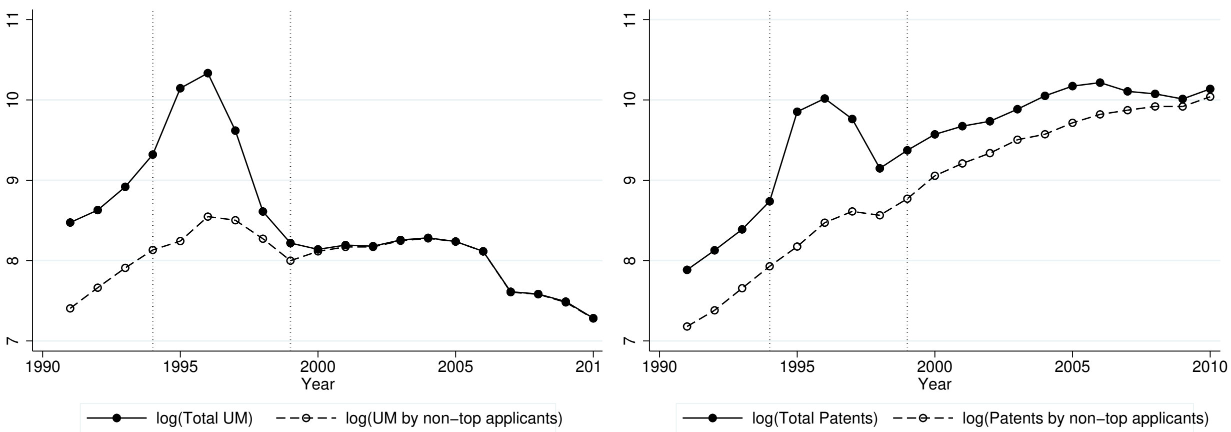
that the impact of the GL and YL periods are both positive and statistically significant on both patents and utility models. At the same time, the magnitude of increase is much larger for utility models than that for patents. In addition, the effect of R&D subsidies is also larger for utility models than that for patents. Yet, since the measures on R&D subsidies and private R&D spending are at the industry-year level, a limitation is that we are unable to further disentangle effects on subsidy recipients from those on non-recipients.[22]

Overall, a stronger performance in utility models in Table 6 appears to be associated with the fact that the government increased R&D subsidies especially for firms with higher returns (Table 5) and that recipient firms conducted less basic research and more development research (Table 4). That is, the government's strategic subsidization during the GL period is likely to have affected firms' R&D activities by changing their incentives. As a result, this seems to have resulted in a stronger improvement in minor and incremental innovations.

According to a study, "the role of patents and utility models in innovation and economic growth varies by level of economic development" (Kim et al. 2012, p.358). Based on empirical evidence from Korea, the authors find that incremental innovations were more important when Korean firms were technologically lagging during 1970-1986 but there was a "role reversal" afterwards as firms relied "less on minor innovations for its performance and more on inventive, patentable innovations" (Kim et al. 2012, p.372). In light of their findings, it is possible that the stronger performance in utility models during the GL period was perhaps driven by firms that were lagging. To explore this possibility, we identify the "top applicants" in the data, which we define as the top-10 firms with the largest cumulative count of patents and utility models during the pre-WTO period. In Figure 4a, we plot the logarithm of utility models produced by all domestic firms in a solid line and that by all non-top applicants in a dashed line. Non-top applicants are defined as all domestic firms except for the top-10 applicants. Similarly, Figure 4b shows the trends for patents.

We begin by examining the overall production of utility models and patents by all domestic firms. This is captured by the solid line in each panel in Figure 4. Utility models

[22] Relatedly, Almus and Czarnitzki (2003) and Bronzini and Piselli (2016) compare innovation outcomes between firms that received public R&D subsidies and the control group of non-recipient firms. Both find that the beneficiary firms increase their innovation activities and patent applications compared to their counterparts.



(a) Utility Models

(b) Patents

Figure 4: Trend of Patents and Utility Models

Notes: In Figure 4a (Figure 4b), the solid line shows the logarithm of utility models (patents) produced by all domestic firms. Similarly, the dashed line in Figure 4a (Figure 4b) shows the logarithm of utility models (patents) produced by all non-top applicants.

and patents differ in their trend paths as well as magnitude of change. Whereas both patents and utility models increased during the GL period, the magnitude of increase for utility models is larger. Moreover, apart from the GL period, utility model has relatively a flat trend while patents show a clear increasing trend. Such different trend paths are indeed consistent with our prior that the role of patents is becoming more important than that of utility models.

Next, we examine the dashed lines which capture the trends of non-top applicants. In both panels, we find a slight increase during the GL period but the magnitude of increase in patents produced by the non-top applicants is very small in Figure 4b. The vertical distance between the solid and dashed lines in each panel shows the contribution from the top-10 applicants. Figure 4a shows that during the GL period, even the top applicants actively produced utility models. That is, the strong performance of utility models during the GL period was not merely driven by firms that were technologically lagging or lacked resources. At the same time, soon after the end of the GL period, the solid and dashed lines almost overlap. This implies that the top-10 applicants rarely produced utility models during the YL period.[23]

[23]The top-10 applicants include firms such as Hyundai Motor Company, LG Electronics Inc., Samsung

Altogether, Figure 4 shows that utility models and patents followed different trends over time. Yet, both show a positive deviation from its trend during the GL period, with the magnitude of increase being much larger for utility models. Such improvement in utility models was clearly not driven by lagging firms.

7 Discussions

7.1 Implications

Our main findings can be summarized as follows. First, the government increased R&D subsidies significantly during the GL period, but such increase did not persist once the YL period began. Second, increased subsidies were especially targeted towards the types of firms/industries that had higher returns, and such firms conducted less basic research and more development research upon receiving subsidies. Lastly, improvements in innovations were more significant for utility models that require a lower level of inventive step, as opposed to patents.

Based on these empirical findings, we derive the following implications. First, our study highlights the difficulty of balancing goals in allocating R&D subsidies, given various degrees of spillovers and expected returns arising at different points in time. Our empirical evidence shows that the strategic use of subsidies during the GL period mostly improved rather minor and incremental innovations. Since policymakers are often hard-pressed to deliver quick outcomes under a tight budget constraint, such strategic tendency is likely to be also applicable to other empirical contexts. Given that R&D activities with high risk but large potential spillovers are especially likely to be under-supplied without government subsidization, our findings suggest that those R&D activities may still be under-supplied with the presence of strategic subsidization. Answering the question as to how much of an increase in fundamental innovations would have occurred during the

Electronics Co., Ltd, Orion Electric Co., Ltd, and Kia Motors Corporation. All top applicants belong in industries related to motors, electrical equipment, or machinery, which are the largest utility model producers (see Table A1). One may wonder how the drop in aggregate count of utility models during the YL period in Figure 4a can be reconciled with the positive coefficient for $\mathbb{1}(\text{YL})_t$ in Table 6. The estimation in Table 6 is conducted at the industry level, and the top applicants were all in one of the aforementioned three industries. The industry level analysis thus shows that once we account for various observable and unobservable covariates, there was an increase in utility models during the YL period compared to the pre-WTO period.

GL period had subsidies not been used strategically is beyond the scope of this paper. Nevertheless, our findings suggest that to the extent that more subsidy resources can alternatively be allocated to R&D activities with high social returns and spillovers, they can better improve the potential for advancing technology and innovations.

Second, our findings have implications on designing regulatory environment for R&D subsidies. A permissive regulatory environment enables a government to freely allocate R&D subsidies in pursuit of its prioritized goals. Thus, a permissive regulatory environment may not necessarily be more favorable in inducing breakthrough innovations, if a government allocates R&D subsidies to pursue other goals. Therefore, perhaps regulations on R&D subsidies can better support innovations with large social returns if permissiveness or restrictiveness of regulations is designed to be research-type dependent.

7.2 Additional Evidence on Trade Patterns

Since the regulatory environment was imposed by the WTO that governs the rules of trade, another potential outcome of interest is trade. The theoretical literature shows that R&D subsidies can help domestic firms to capture greater profits in imperfectly competitive markets (Haaland and Kind 2006, 2008; Leahy and Neary 2001, 2009), and that specifically targeted R&D subsidies can be used as beggar-thy-neighbor policies in the absence of the WTO subsidy rules (Koh and Lee 2020). Therefore, we investigate whether there were any changes in trade patterns in line with the WTO subsidy rules.

The dependent variable that we use is $log\left(\frac{\text{No. of exports}}{\text{No. of imports}}\right)_{i,k,t}$, which shows the ratio of the number of export goods to the number of import goods, for an industry (k) and a partner country (i) in a year (t). Using the United Nations Comtrade database, we count the number of export and import varieties between Korea and each one of the G7 countries at the HS six-digit level for each of the 16 industries in a year.[24] This ratio, which captures trade patterns on whether the number of export goods increased relative to the number of import goods, is likely to be affected by the WTO subsidy rules. This is because the key feature of the GL period is that R&D subsidies targeting specific firms in export or import sectors were also permitted even when those subsidies caused "adverse effects" to another member. During the GL period, a government could thus legitimately

[24]We use the HS-ISIC concordance table from the Forum for Research in Empirical International Trade to aggregate and match the data in HS codes (six-digit level) to our survey data in ISIC codes (three-digit level).

Table 7: Trade Patterns

	(1)	(2)	(3)	(4)
Dependent variable:		$log\left(\frac{\text{No. of exports}}{\text{No. of imports}}\right)_{i,k,t}$		
$log\left(\frac{\text{No. of exports}}{\text{No. of imports}}\right)_{i,k,t-1}$	0.896***	0.900***	0.694***	0.730***
	(0.012)	(0.013)	(0.065)	(0.058)
$\mathbb{1}(\text{GL})_t$	0.022	0.023	0.044***	0.036**
	(0.028)	(0.030)	(0.016)	(0.015)
$\mathbb{1}(\text{YL})_t$	-0.045	-0.048	0.002	-0.002
	(0.122)	(0.123)	(0.016)	(0.018)
Dev share$_{k,t-1}$	0.114***		0.056	
	(0.039)		(0.062)	
Basic share$_{k,t-1}$		-0.131*		-0.182***
		(0.069)		(0.061)
Number of Obs.	2,121	2,121	2,121	2,121
Method	OLS	OLS	GMM	GMM
R-squared	0.883	0.882		
P-value for AR(2)			0.802	0.797
P-value for Hansen test			0.481	0.352
DF for Hansen test			6	6

Notes: The estimation is conducted at the partner country–industry–year level. There are 7 partner countries, 16 industries, and 20 years and 119 observations with missing information. After accounting for some missing observations in the survey data, 2,121 observations are used in the estimation. Asterisks ***/**/* denote $p<0.01$, $p<0.05$, $p<0.1$, respectively. Standard errors are clustered at the year level. Across all specifications, we include the following variables: log(R&D subsidies)$_{k,t-1}$, log(Private R&D)$_{k,t-1}$, a linear time trend, president fixed effects, the Asian Financial Crisis fixed effect. In the GMM estimation, we use fourth and fifth lags of log(R&D subsidies) and log(Private R&D) as instruments.

use R&D subsidies to bring commercial advantages to domestic firms in export or import sectors by fostering the development of new or higher-quality products or by decreasing quality-adjusted prices. However, besides R&D subsidies and the WTO subsidy rules, there are also other factors that may have affected trade patterns. Therefore, changes in trade patterns are likely to arise as indirect consequences with a potential time lag. This makes it difficult to establish a causal relationship without using more detailed micro level data. We thus present our findings as evidence on the correlational relationship given such limitations.

Table 7 summarizes our findings. Given a strong persistence in trade patterns observed in the data, we include the lagged dependent variable in all specifications. The OLS estimates in columns (1) and (2) show that there is no statistically significant change in trade patterns with respect to the GL or YL periods. Yet, a lower share of basic research or a higher share of development research seems to be advantageous in improving trade patterns. The GMM estimates in columns (3) and (4) show that trade patterns improved during the GL period, but this did not persist once the YL period began. Therefore, Table 7 provides preliminary evidence on the possibility that the regulatory environment seems to have improved trade patterns via strategic subsidization.

8 Conclusion

In this paper, we empirically examine the extent to which a government's R&D subsidization changed in response to the regulatory environment imposed by the WTO. We find that the Korean government substantially increased R&D subsidies for firms during the GL period, and selectively did so for certain firms and industries that had higher returns. Innovation outcomes improved, but mostly so for rather minor and incremental innovations. Therefore, our empirical findings imply that a permissive regulatory environment does not necessarily maximize the potential for innovations, since a government can use subsidies as a means to seek immediate commercial success.

We investigate the validity of our results using a series of robustness checks. Such exercises confirm that our main findings remain robust. However, since our empirical study is limited to evidence from one country, we acknowledge that the external validity of our findings may not be readily established. Although the magnitude of effects may differ, however, underlying incentives to seek immediate commercial returns using R&D subsidies are likely to be applicable to other countries. Therefore, it would be interesting to extend this analysis to other countries using additional data and to investigate heterogeneous aspects. For example, countries with a greater reliance on government R&D subsidies or a higher R&D intensity may be more sensitive to the changes in regulatory environment.

References

Acharya, V. V., R. P. Baghai, and K. V. Subramanian (2013, 11). Labor Laws and Innovation. *The Journal of Law and Economics 56*(4), 997–1037.

Acharya, V. V., R. P. Baghai, and K. V. Subramanian (2014, 1). Wrongful Discharge Laws and Innovation. *The Review of Financial Studies 27*(1), 301–346.

Aghion, P., J. Cai, M. Dewatripont, L. Du, A. Harrison, and P. Legros (2015). Industrial Policy and Competition. *American Economic Journal: Macroeconomics 7*(4), 1–32.

Ahn, D. (2007). Legal Issues for R&D Subsidies in the WTO System. *Korean Forum on International Trade and Business Law 16*(2), 357–384.

Akcigit, U., D. Hanley, and N. Serrano-Velarde (2021, 1). Back to Basics: Basic Research Spillovers, Innovation Policy, and Growth. *The Review of Economic Studies 88*(1), 1–43.

Almus, M. and D. Czarnitzki (2003, 4). The Effects of Public R&D Subsidies on Firms' Innovation Activities. *Journal of Business & Economic Statistics 21*(2), 226–236.

Amable, B., I. Ledezma, and S. Robin (2016). Product Market Regulation, Innovation, and Productivity. *Research Policy 45*(10), 2087–2104.

Arrow, K. J. (1962). Economic Welfare and the Allocation of Resources for Invention. pp. 609–626. Princeton University Press.

Audretsch, D. B., A. N. Link, and J. T. Scott (2002). Public/Private Technology Partnerships: Evaluating SBIR-supported Research. *Research Policy 31*(1), 145–158.

Bagwell, K. and R. W. Staiger (2001, 05). Domestic Policies, National Sovereignty, and International Economic Institutions. *The Quarterly Journal of Economics 116*(2), 519–562.

Bagwell, K. and R. W. Staiger (2006). Will International Rules on Subsidies Disrupt the World Trading System? *American Economic Review 96*(3), 877–895.

Balsmeier, B. (2017). Unions, Collective Relations Laws and R&D Investment in Emerging and Developing Countries. *Research Policy 46*(1), 292–304.

Barbosa, N. and A. P. Faria (2011). Innovation across Europe: How important are institutional differences? *Research Policy 40*(9), 1157–1169.

Barrett, S. (1994). Strategic Environmental Policy and International Trade. *Journal of Public Economics 54*(3), 325–338.

Beason, R. and D. E. Weinstein (1996). Growth, Economies of Scale, and Targeting in Japan (1955-1990). *The Review of Economics and Statistics 78*(2), 286–295.

Beck, M., C. Lopes-Bento, and A. Schenker-Wicki (2016). Radical or Incremental: Where Does R&D Policy Hit? *Research Policy 45*(4), 869–883.

Blind, K. (2012). The Influence of Regulations on Innovation: A Quantitative Assessment for OECD Countries. *Research Policy 41*(2), 391–400.

Bloom, N., J. Van Reenen, and H. Williams (2019, 8). A Toolkit of Policies to Promote Innovation. *Journal of Economic Perspectives 33*(3), 163–184.

Bronzini, R. and E. Iachini (2014). Are Incentives for R&D Effective? Evidence from a Regression Discontinuity Approach. *American Economic Journal: Economic Policy 6*(4), 100–134.

Bronzini, R. and P. Piselli (2016). The Impact of R&D Subsidies on Firm Innovation. *Research Policy 45*(2), 442–457.

Brown, D. K., A. V. Deardorff, and R. M. Stern (1993). *International Labor Standards and Trade: A Theoretical Analysis*, Volume 333. Institute of Public Policy Studies, University of Michigan USA.

Carlino, G. and W. R. Kerr (2015). Agglomeration and Innovation. In G. Duranton, J. V. Henderson, and W. C. Strange (Eds.), *Handbook of Regional and Urban Economics* (1 ed.)., Chapter 6, pp. 349–404.

Cheung, J. and D. Ahn (2011). Studies on WTO Consistency of Tax and Fiscal Policies. *Korea Institute of Public Finance*.

David, P. A., B. H. Hall, and A. A. Toole (2000). Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence. *Research Policy 29*(4), 497–529.

Dimos, C. and G. Pugh (2016). The Effectiveness of R&D subsidies: A Meta-Regression Analysis of the Evaluation Literature. *Research Policy 45*(4), 797–815.

Duan, Y., T. Ji, Y. Lu, and S. Wang (2021). Environmental Regulations and International Trade: A Quantitative Economic Analysis of World Pollution Emissions. *Journal of Public Economics 203*, 104521.

Ederington, J. and J. Minier (2003). Is Environmental Policy A Secondary Trade Barrier? An Empirical Analysis. *Canadian Journal of Economics/Revue canadienne d'économique 36*(1), 137–154.

Einiö, E. (2014, 10). R&D Subsidies and Company Performance: Evidence from Geographic Variation in Government Funding Based on the ERDF Population-Density Rule. *The Review of Economics and Statistics 96*(4), 710–728.

Encaoua, D., D. Guellec, and C. Martínez (2006). Patent Systems for Encouraging Innovation: Lessons from Economic Analysis. *Research Policy 35*(9), 1423–1440.

Francis, B. B., I. Kim, B. Wang, and Z. Zhang (2018). Labor Law and Innovation Revisited. *Journal of Banking & Finance 94*, 1–15.

Gallini, N. T. (1992, 5). Patent Policy and Costly Imitation. *The RAND Journal of Economics 23*(1), 52–63.

Gallini, N. T. (2002). The Economics of Patents: Lessons from Recent U.S. Patent Reform. *Journal of Economic Perspectives 16*(2), 131–154.

Garcia, R. and R. Calantone (2002, 3). A Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review. *Journal of Product Innovation Management 19*(2), 110–132.

Griffith, R. and G. Macartney (2014, 3). Employment Protection Legislation, Multinational Firms, and Innovation. *The Review of Economics and Statistics 96*(1), 135–150.

Grossman, G. M. and E. L.-C. Lai (2004, December). International Protection of Intellectual Property. *American Economic Review 94*(5), 1635–1653.

Haaland, J. and H. J. Kind (2006). Cooperative and Non-cooperative R&D Policy in an Economic Union. *Review of World Economics 142*(4), 720–745.

Haaland, J. I. and H. J. Kind (2008). R&D Policies, Trade and Process Innovation. *Journal of International Economics 74*(1), 170–187.

Henson, S. and S. Jaffee (2008). Understanding Developing Country Strategic Responses to the Enhancement of Food Safety Standards. *The World Economy 31*(4), 548–568.

Holger, G. and E. Strobl (2007, May). The Effect of R&D Subsidies on Private R&D. *Economica 74*(294), 215–234.

Hottenrott, H., C. Lopes-Bento, and R. Veugelers (2017). Direct and Cross Scheme Effects in a Research and Development Subsidy Program. *Research Policy 46*(6), 1118–1132.

Howell, S. T. (2017, 4). Financing Innovation: Evidence from R&D Grants. *American Economic Review 107*(4), 1136–1164.

Howse, R. (2020, August). Making the WTO (Not So) Great Again: The Case Against Responding to the Trump Trade Agenda Through Reform of WTO Rules on Subsidies and State Enterprises. *Journal of International Economic Law 23*(2), 371–389.

Jaffe, A. B. (2000). The U.S. Patent System in Transition: Policy Innovation and the Innovation Process. *Research Policy 29*(4), 531–557.

Kim, Y. K., K. Lee, W. G. Park, and K. Choo (2012). Appropriate Intellectual Property Protection and Economic Growth in Countries at Different Levels of Development. *Research Policy 41*(2), 358–375.

Koh, Y. and G. M. Lee (2020). A Ricardian Rationale for the WTO Rules on R&D Subsidies. *Economics Letters 196*, 109500.

Lach, S. (2002, 12). Do R&D Subsidies Stimulate or Displace Private R&D? Evidence from Israel. *The Journal of Industrial Economics 50*(4), 369–390.

Leahy, D. and J. P. Neary (2001, 1). Robust Rules for Industrial Policy Open Economies. *The Journal of International Trade & Economic Development 10*(4), 393–409.

Leahy, D. and J. P. Neary (2009). Multilateral Subsidy Games. *Economic Theory 41*(1), 41–66.

Lee, G. M. (2016). Handbook of Commercial Policy Chapter 4 - Subsidies and Countervailing Duties. Volume 1, pp. 161–210. North-Holland.

Lerner, J. (1999). The Government as Venture Capitalist: The Long-Run Impact of the SBIR Program. *The Journal of Business 72*(3), 285–318.

Marino, M., S. Lhuillery, P. Parrotta, and D. Sala (2016). Additionality or Crowding-Out? An Overall Evaluation of Public R&D Subsidy on Private R&D Expenditure. *Research Policy 45*(9), 1715–1730.

Martin, S. and J. T. Scott (2000). The Nature of Innovation Market Failure and the Design of Public Support for Private Innovation. *Research Policy 29*(4), 437–447.

Mavroidis, P. C., P. A. Messerlin, and J. M. Wauters (2008). *The Law and Economics of Contingent Protection in the WTO*. Edward Elgar Publishing, Inc.

Moser, P. (2005). How Do Patent Laws Influence Innovation? Evidence from Nineteenth-Century World's Fairs. *American Economic Review 95*(4), 1214–1236.

OECD (2019). OECD Main Science and Technology Indicators R&D. Highlights 2019. Technical report, Directorate for Science, Technology and Innovation.

OECD (2021). R&D Tax Incentives: Korea, 2020. Technical report, Directorate for Science, Technology and Innovation.

Palmer, K., W. E. Oates, and P. R. Portney (1995). Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm? *Journal of Economic Perspectives 9*(4), 119–132.

Park, J. S. and S. G. Park (2007). A Study on WTO Subsidies Application of Defense R&D Project. *Journal of International Trade and Industry Studies 12*(2), 131–152.

Porter, M. E. (1991). America's Green Strategy. *Scientific American 264*.

Porter, M. E. and C. van der Linde (1995, 5). Toward a New Conception of the Environment-Competitiveness Relationship. *The Journal of Economic Perspectives 9*(4), 97–118.

Roodman, D. (2009a, 2). A Note on the Theme of Too Many Instruments. *Oxford Bulletin of Economics and Statistics 71*(1), 135–158.

Roodman, D. (2009b, 3). How to do Xtabond2: An Introduction to Difference and System GMM in Stata. *The Stata Journal 9*(1), 86–136.

Rzakhanov, Z. (2008). Regulatory Policy, Value of Knowledge Assets and Innovation Strategy: The Case of the Orphan Drug Act. *Research Policy 37*(4), 673–689.

Sanyal, P. and S. Ghosh (2013, 3). Product Market Competition and Upstream Innovation: Evidence from the U.S. Electricity Market Deregulation. *The Review of Economics and Statistics 95*(1), 237–254.

Schilling, M. (2013). *Strategic Management of Technological Innovation*. New York: McGraw-Hill.

Scotchmer, S. (1991). Standing on the Shoulders of Giants: Cumulative Research and the Patent Law. *Journal of Economic Perspectives 5*(1), 29–41.

Smith, D. (2020). The Effects of Federal Research and Development Subsidies on Firm Commercialization Behavior. *Research Policy 49*(7), 104003.

Staiger, R. W. and A. O. Sykes (2017). How Important Can the Non-violation Clause Be for the GATT/WTO? *American Economic Journal: Microeconomics 9*(2), 149–87.

Sykes, A. O. (2005). Subsidies and Countervailing Measures BT - The World Trade Organization: Legal, Economic and Political Analysis. pp. 1682–1706. Boston, MA: Springer US.

Sykes, A. O. (2010, October). The Questionable Case for Subsidies Regulation: A Comparative Perspective. *Journal of Legal Analysis 2*(2), 473–523.

Szücs, F. (2020). Do Research Subsidies Crowd Out Private R&D of Large Firms? Evidence from European Framework Programmes. *Research Policy 49*(3), 103923.

Wallsten, S. J. (2000, 8). 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.

Zuniga-Vicente, J. A., C. Alonso-Borrego, F. J. Forcadell, and J. I. Galan (2014). Asessing the Effect of Public Subsidies on Firm R&D Investment: A Survey. *Journal of Economic Surveys 28*(1), 36–67.

Žigić, K. (2000). Strategic Trade Policy, Intellectual Property Rights Protection, and North–South Trade. *Journal of Development Economics 61*(1), 27–60.

A Appendices

A.1 Additional Summary of Statistics

Table A1: Industry-Specific Statistics for Firms.

Industry	Avg R&D Amount	Subsidized Share	Dev. Share	Patent	UM
Food products and beverages	1,271.70	3.23%	64.18%	10,731	988
Textiles	1,242.94	10.78%	65.12%	3,227	322
Wearing apparel and fur	1,092.40	1.78%	71.39%	882	1,196
Leather products and footwear	1,253.81	3.38%	83.65%	1,118	1,317
Pulp, paper, and paper products	925.31	3.66%	68.66%	1,056	443
Printing, reproduction of recorded media	1,460.28	3.00%	78.59%	1,748	682
Coke, refined petroleum, and nuclear fuel	9,136.08	6.44%	64.37%	908	74
Chemicals and chemical products	1,995.88	6.66%	60.69%	7,902	470
Rubber and plastic products	1,664.24	3.92%	79.38%	26,415	14,893
Non-metallic mineral products	1,453.41	5.90%	66.15%	25,086	7,656
Basic metals	2,892.94	6.64%	70.16%	11,348	1,985
Fabricated metal products	779.69	10.91%	74.10%	3,279	848
Electrical equipment	3,250.80	8.91%	73.95%	106,451	22,297
Other machinery and equipment	1,457.90	13.69%	77.76%	69,858	24,005
Motor vehicles, trailers, and semitrailers	10,545.95	1.92%	73.56%	91,426	69,317
Other transport equipment	10,376.96	18.12%	76.24%	678	673

Notes: Average R&D amounts are in real million Korean won, deflated by the CPI (base year 2010). R&D amount, subsidized share, and development research share show the average values per firm for given industry during our sample period. The number of patent (utility model) applications shows the total count of patents (utility models) produced by all domestic firms from 1991 to 2010 for given industry.

A.2 Difference-in-Differences Analysis

Using the sample of firms and research institutes from 1991 to 1999 (i.e. the pre-WTO and GL periods), we estimate the following specification:

$$y_{kt} = \alpha + \beta \cdot \mathbb{1}(\text{Firm}) \times \mathbb{1}(\text{GL})_t + \gamma \cdot \mathbb{1}(\text{Firm}) + \rho \cdot \mathbb{1}(\text{GL})_t + \phi_t + \mu_k + \epsilon_{kt}. \tag{3}$$

We conduct our analysis at the industry (k) and year (t) level, since the size class information is not available for research institutes. $\mathbb{1}$(Firm) equals one for firms and zero for research institutes. The rest of the notations are the same as in equation (1). The key parameter of interest is β. We use the data on pre-WTO period and the GL period only, so that the treatment is defined over firms during the GL period.

In Table A2, the outcomes of interest are R&D subsidies and private R&D spending. In columns (1) to (2), we find that the impact of $\mathbb{1}(\text{Firm}) \times \mathbb{1}(\text{GL})_t$ on log(R&D subsidies)$_{k,t}$ is positive and statistically significant at 1%. In columns (3) to (4), however, we find the impact on log(Private R&D)$_{k,t}$ to be statistically insignificant. This suggests that there was a significant increase in R&D subsidies for firms once the GL period began, compared to the changes in subsidies observed for research institutes. However, this is not the case for private R&D spending. Thus, the DID estimates are consistent with our main findings.

In Table A3, we now use the count of patents and utility models as the dependent variable, respectively. In columns (1) and (2), we do not find any statistically significant increase in patents by firms once the GL period began, compared to the changes in patents by research institutes. In columns (3) and (4), however, the treatment effect on utility models is positive and statistically significant at 10%. In line with our main findings, improvements in incremental and minor innovations were relatively stronger.

Table A2: DID Analysis of R&D spending —1991-1999

Dep. variable:	log(R&D subsidies)$_{k,t}$		log(Private R&D)$_{k,t}$	
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{Firm}) \times \mathbb{1}(\text{GL})_t$	1.7260***	1.7361***	-0.0898	-0.1035
	(0.2666)	(0.2453)	(0.2803)	(0.2789)
$\mathbb{1}(\text{Firm})$	-3.9718***	-3.9505***	1.6619	1.6560
	(0.5367)	(0.5365)	(0.9133)	(0.9208)
$\mathbb{1}(\text{GL})_t$	-0.9384**	-0.8394**	0.2432	0.3018
	(0.3870)	(0.2780)	(0.3272)	(0.3680)
Observations	235	235	235	235
R-squared	0.885	0.887	0.852	0.853
Linear time trend	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Size-class FE	Yes	Yes	Yes	Yes
President FE		Yes		Yes
Asian financial crisis		Yes		Yes

Notes: The estimation is conducted at the industry–year level using data on firms and research institutes from 1991 to 1999. There are 16 industries for firms and 10 industries for research institutes. However, from 1996, data on additional 5 industries for research institutes are included in the survey and thus we also include them in our analysis. After accounting for some missing observations at the industry–year level in the survey data, we end up with 235 observations used in the estimation. Asterisks ***/**/* denote p<0.01, p<0.05, p<0.1, respectively. The amounts are in real million Korean won, deflated by the CPI (base year 2010). Standard errors are clustered at the year level.

Table A3: DID Analysis of Innovation Outcomes —1991-1999

Dep. variable:	$\log(\text{Patents})_{k,t}$		$\log(\text{UM})_{k,t}$	
	(1)	(2)	(3)	(4)
$\mathbb{1}(\text{Firm}) \times \mathbb{1}(\text{GL})_t$	0.1994	0.1994	0.2115*	0.2115*
	(0.1328)	(0.1335)	(0.1087)	(0.1093)
$\mathbb{1}(\text{Firm})$	2.2037***	2.2037***	3.2683***	3.2683***
	(0.0973)	(0.0979)	(0.0834)	(0.0838)
$\mathbb{1}(\text{GL})_t$	0.0316	-0.1127	0.2999	0.0874
	(0.2400)	(0.1286)	(0.1928)	(0.1051)
Observations	288	288	288	288
R-squared	0.894	0.897	0.875	0.878
Linear time trend	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Size-class FE	Yes	Yes	Yes	Yes
President FE		Yes		Yes
Asian financial crisis		Yes		Yes

Notes: The estimation is conducted at the industry–year level using data on firms and research institutes from 1991 to 1999. There are 16 industries for firms and research institutes across 9 years, respectively (i.e. $16 \times 2 \times 9 = 288$). There are no missing observations since no variables from the survey data are used. Asterisks ***/**/* denote $p<0.01$, $p<0.05$, $p<0.1$, respectively. Standard errors are clustered at the year level.

A.3 Industry Classification

Table A4: Industry Classification in Table 5.

	(1) Sales	(2) Patents	(3) Utility Models
	Subsidy	Subsidy	Subsidy
Food products and beverages	H	H	L
Textiles	L	L	L
Wearing apparel and fur	H	H	H
Leather products and footwear	H	L	H
Pulp, paper, and paper products	H	H	H
Printing, reproduction of recorded media	L	H	H
Coke, refined petroleum, and nuclear fuel	H	L	L
Chemicals and chemical products	L	L	L
Rubber and plastic products	H	H	H
Non-metallic mineral products	L	H	H
Basic metals	H	L	L
Fabricated metal products	L	L	L
Electrical equipment	L	L	L
Other machinery and equipment	L	H	H
Motor vehicles, trailers, and semitrailers	L	H	H
Other transport equipment	H	L	L

Notes: In each of the three columns, the industries that have higher (lower) values of the given criteria are marked as “H” (“L”).