政府研发补贴何时有助于创新？环境力量对不同专利类型的影响

When do government R&D subsidies help innovations? Implications of environmental forces for different patent types

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Abstract: Although many firms have received government subsidies to support their research and development (R&D), an understanding of their impact on innovation remains unclear. In response, the authors, based on the patent classifications adopted by many countries across the globe, divide innovation into three forms, including invention patents, utility model patents, and design patents, and study how government R&D subsidies influence each of them. Because external environments play an important role affecting firms' strategy and outcomes, the authors investigate how technological turbulence and market uncertainty directly affect—and in combination with R&D subsidies—influence each patent type. Results from a longitudinal panel dataset of 463 high-tech firms across seven years show that R&D subsidies only influence inventions and utility models. The results further indicate that technological turbulence not only affects inventions directly but also interacts with R&D subsidies to impact inventions. In contrast, market uncertainty exerts opposing direct effects on all patent types, whereas R&D subsidies help alleviate its downside influence on utility models. More results and their implications to theory and practice are discussed toward the end.

Keywords: panel data; subsidies; innovation; technological turbulence; market uncertainty; high-tech firms

1. Introduction

The relationship between research and development (R&D) subsidies and innovation has received a great deal of attention in recent years (Czarnitzki et al., 2007; Hong et al., 2016; Howell, 2017; Zhou et al., 2020). R&D subsidies are grants offered to private sectors by their government to fund projects that have the potential to advance knowledge and technology. In the United States, for example, Tesla received various R&D subsidies including one from the California government for developing energy storage technology, which is critical to the success of electric pick-up and semi-trucks (LA Times 2015).[1] Surprisingly, although many organizations continue to receive R&D subsidies, empirical evidence of their effectiveness is inconclusive, with some showing positive outcomes (Conti, 2018; Czarnitzki et al., 2011; Howell, 2017) and some suggesting otherwise (Czarnitzki et al., 2007; Hong et al., 2016; Szücs, 2018; Zhou et al., 2020).

Such inconclusive findings may result from applying the total patent counts, an aggregate measure of innovation, rather than the individual forms of patents, i.e., inventions, utility models, and designs to represent the multi-facets of innovations[2] (see Table 1 for our review of literature). Indeed, not all innovations are created equally (Kim et al., 2012). Because inventions reflect a much higher degree of innovation than the other two types of patents, separating them from each other enables us to better understand when R&D subsidies work. Furthermore, resource dependence theory argues that external environmental forces continue to shape how firms operate and strategize for competitive performance (Schuster and Holtbrügge, 2014). Procuring additional resources such as R&D subsidies may provide a buffer for a firm to cope with threats and opportunities arising from external environments. Against this backdrop, the current study aims at investigating how R&D subsidies work under various environmental forces and for different patent types. Through integrating the literature on innovation with government subsidies and resource dependence theory, we seek to answer the following questions:

(1) Do R&D subsidies help or hurt a firm's innovations, measured separately by invention patents, utility model patents, and design patents?

(2) What roles do R&D subsidies play in the presence of technological turbulence and market uncertainty that potentially influence each type of patent?

Based on a set of panel data collected from 463 high-tech firms publicly traded in China, this study finds R&D subsidies affect inventions and utility models positively; but, design patents do not. Further, we explore the boundaries of R&D subsidies affecting firm innovation and results show that R&D subsidies strengthen the effects on invention patents under technological turbulence and on utility patents under market uncertainty. Through this study, we attempt to make at least two contributions. First, the link between R&D subsidies and firm innovation has been subject to intense scholarly inquiry. Unfortunately, results remain mixed, suggesting the need for a richer assessment of R&D subsidies. We apply the individual forms of patents, i.e., inventions, utility models, and designs instead of the total patent counts, a common measure of firm innovation used in the existing literature, providing stronger insights that help resolve the debate on whether R&D subsidies are good for innovation. Second, our review of the literature shown in

Table 1 suggests that previous research that investigates boundary conditions of R&D subsidies and firm innovation mainly focuses on firms' individual characteristics such as size, age and ownership rather than external environments. Examining environmental forces as boundary conditions provides firms and policymakers with an alternative insight on the relationship between R&D subsidies and innovation outcomes. Our findings offer implications for policymakers by encouraging them to offer R&D subsidies to private sectors, but they should be mindful about the consequences of subsidies and the influences of environmental factors on different types of patents.

[Insert Table 1 about here]

The remainder of the study is arranged as follows. Section 2 reviews the relevant literature and develops a theoretical framework that explains how each patent type is affected by R&D subsidies. Section 3 illustrates our data and methods. Empirical findings are shown in Section 4. Section 5 discusses the theoretical and practical implications of our findings along with suggestions for future research.

2. Theoretical background and conceptual framework

Innovation has long been recognized as an important driving force to sustain the growth of an economy (Hong et al., 2016). Unfortunately, while some firms lack incentives to innovate (Zhou et al., 2020), others are motivated to invent but face financial constraints (Chen et al., 2018; Guo et al., 2018; Kaufmann and Tödtling, 2002). As a result, a shortage of either incentives or financial resources may hamper firms and their economy from reaching a socially optimal level of R&D investment. For their nations to thrive and stay competitive, many governments provide private sectors with financial resources including R&D subsidies to sustain their innovation programs.

Recognizing the criticality of R&D subsidies, research has emerged to study how subsidies relate to innovations (Boeing, 2016; Hong et al., 2016; Zhou et al., 2020). One stream of research has shown that R&D subsidies have direct and positive bearings on firm innovations, measured by total patent counts. For example, Czarnitzki et al. (2011) found evidence that R&D subsidies increase innovations. Huergo and Moreno (2014) examined over 2,000 Spanish firms during 2002-2005 and confirmed that the European subsidy program affected the probability of these firms applying for patents. Chai and Shih (2016) compared a sample of firms funded by the Danish National Advanced Technology Foundation with those unfunded and found that funded firms obtained more patents than their counterparts.

In contrast, some researchers found no empirical evidence for the positive role of R&D subsidies on innovations. For example, Cappelen et al. (2012) investigated a sample of Norwegian firms and found that SkatteFUNN—a government subsidies program—affected neither their number of new products launched to the market nor patent applications. Other studies that surveyed firms in Germany (Czarnitzki et al., 2007), the United States (Wallsten, 2000), and China (Hong et al., 2016; Zhou et al., 2020) similarly revealed negative or insignificant impacts of R&D subsidies on patent applications.

We contend that the inconsistency of prior results could be driven in part by how innovation is operationalized. Although it is not uncommon to use the number of patent counts to measure innovation, using the total counts of all types of patents to represent innovation can potentially disguise the actual effects of R&D subsidies. Notably, some regions and countries, such as Germany, France, Italy, Japan and China[3], classify patents into three groups: inventions, utility models, and designs—in accordance with their current patent laws. Any technical solution new on a product or a process can be filed for an invention patent. Its application, however, requires substantial evaluations of novelty, inventive steps, and practical applicability. Utility model patents are awarded to making small improvements to, and adaptations of, existing products or that have a short commercial life. Utility model patent applications are granted primarily on a registration basis without substantive examination and thus generally represent minor or incremental innovations. Design patents are awarded for unique visual qualities of a product such as size, shape, material finish, colour, graphics, and alike. Because technical originality is not required for design patents, separating inventions and utility models from designs enable us to have a more fine-grained understanding of when and how R&D subsidies work, providing insights to academia, practitioners, and policy makers.

As previously mentioned, empirical evidence regarding R&D subsidies on innovation remains unclear, and their strategic implications are still inconclusive (Antolín-López et al., 2015; Zhou et al., 2020). While it is important to distinguish patent types from each other, conflicting results in prior research further suggest the need to uncover contingency factors. More specifically, resource dependence theory (Schuster and Holtbrügge, 2014) posits that a firm's external environments may encourage or constrain the efficacy and popularity of its strategy or organizational actions. This theory puts further emphasis on complementary resources that can be garnered from outward sources such as board directors, alliances, joint-ventures, and suppliers for explaining firm innovation (Chen et al., 2018). However, firms should not ignore the influence of government agencies as a powerful third actor—one that plays a significant role in determining firms' innovation capabilities and competitive advantages through direct subsidies, tariffs, tax holidays, etc. Especially, R&D subsidies can provide immediate support to alleviate risks and resource constraints, as product innovation is a high-risk and resource-consuming activity.

Moreover, resource dependence theory underscores how resource inadequacies subject firms to uncertainties, which influence their efficiency and choice of resource allocation (Schuster and Holtbrügge, 2014). The unpredictable ebbs and flows of a turbulent environment disrupt a firm's current resource condition, forcing it to strive for more external resources to support its innovation (Paladino, 2008). In other words, emphasizing R&D subsidies as outbound resources, optimizing a firm's innovation outcome relies on the absence of a mismatch between the firm's acquired R&D subsidies and external environments.

Following prior studies, we focus on technological turbulence and market uncertainty, which have profound influences on firms' innovation activities (Paladino, 2008). We examine how each environmental force affects innovation and how it interacts with R&D subsidies to further influence innovation. In what it follows, we synthesize the literature on subsidies with innovation and resource dependence theory to develop our hypotheses.

2.1. Direct effects of R&D subsidies on patent types

Scholars have long suggested that when firms have resources that are valuable, rare, inimitable, and non-substitutable (i.e., so-called VRIN attributes), they can achieve sustainable competitive advantage by implementing fresh value-creating strategies (Barney, 1991; Wernerfelt, 1995). R&D subsidies are resources that possess VRIN attributes. In particular, R&D subsidies can serve as direct financial resource, allowing a firm to recruit talent and test out novel ideas that the firm would otherwise be unable to do so (Howell, 2017). Furthermore, R&D subsidies can serve as political legitimacy, which is an important strategic resource, indirectly attracting more financial resources to motivate firms to engage in innovation (Chen et al., 2018; Zhou et al., 2020). In sum, R&D subsidies help alleviate a firm's financing constraints and further stimulate the firm to increase innovation. For example, Boeing received US$457 million in government grants from 2000 to 2014.[4] Consider Boeing replacing aluminum with carbon fiber—which is stronger and lighter—for the 787 commercial jet's fuselage and wings. Without government R&D subsidies, Boeing might not take their chance to experiment with new technology.

Although R&D subsidies bring in various benefits like those mentioned above, their impacts on each patent type are unlikely to be identical since inventions, utility models, and designs have several key features that set them apart from each other. More specifically, inventions are radically new to the industry, which indicate that inventions need a long-term commitment of substantial resources, including human and financial resources. Thus, the resources of R&D subsidies and generated by R&D subsidies are particularly important under the assumption that organizational resources are limited. Utility models are extensions of existing products or technology, involving a comparatively lower level of inventive step and are less costly than inventions. Thus, R&D subsidies can encourage firms to continue upgrading their existing technology and products, but R&D subsidies may not play a critical role in developing utility model patents, as partial firms can fully cover the exploration costs of utility model patents. In contrast, design patents are granted to products that have changed their graphic or visual qualities, it is unlikely to require substantial resources from a firm. Thus, we posit:

H1: Relative to design patents, R&D subsidies positively affect (a) invention patents and (b) utility model patents, and (c) the effects of R&D subsidies are stronger on invention patents than utility model patents.

2.2. Technological turbulence

The literature defines technological turbulence as the extent of unpredictability, change, and volatility in technology (Tushman and Anderson, 1986). It has been shown to affect the rate and speed of change in new processes and products. Specifically, high technological turbulence suggests that technologies are substituted more quickly, making the value of technologies deteriorate unpredictably (Fernández et al., 2010). Likewise, accelerated technological advancements not only constantly shift industrial standards but also reshape market power (Afuah, 2001). As new opportunities continue to emerge, thanks to changing technology, market powers are redistributed (Fernández et al., 2010). Consequently, more firms are motivated to create new technology or products to disrupt the market standard as in invention patents. Moreover, while technological turbulence creates unpredictability, it also produces opportunities for firms to develop breakthroughs if they continue to configure and reconfigure various resources in new use (Stock et al., 2013; Wilden and Gudergan, 2015).

Despite the direct influences of technological turbulence on different types of innovations discussed previously, its presence is likely to change the effects of R&D subsidies on innovations and such effects may be more prominent on invention patents than utility models and designs. Specifically, relative to utility models and designs, inventions tend to induce higher costs associated with the production of cutting-edge technology (Mugge and Dahl, 2013). Thus, to avoid the pitfall of not recouping their investment in times of high technological turbulence, firms are likely to rely on R&D subsidies, which do not require paying back, to support riskier projects as seen in inventions rather than utility models that are built on existing products and technology. Moreover, high technological turbulence suggests a relatively unpredictable product life cycle (Fernández et al., 2010). Under this circumstance, R&D subsidies offer a much-needed buffer for firms to speed up their efforts in inventions. In contrast, because utility models and designs require little to no technical efforts, R&D subsidies are unlikely to play a significant role in shifting the influences of technological turbulence. In particular, utility model patents, with their exploitative product evolution mechanisms, are not created for the purpose of leap frogging in technology. For example, MP3 player[5] was replaced by its own upgraded version MP4 and MP5. Likewise, because design patents do not require any technical novelty, it appears resistant to the frequent change of technology. Due to the nature of inventions, frequent and unpredictable changes in technology are likely to reinforce firms to increase inventions patenting to prevent illegal exploitation or freeriding by others. We therefore predict that in the presence of high technological turbulence, R&D subsidies influences invention patents more strongly than the other two forms of patents.

H2: Relative to utility model and design patents, technological turbulence strengthens the positive effects of R&D subsidies on invention patents.

2.3. Market uncertainty

Market uncertainty depicts the level of change in customer choices or preferences for products in a specific sector (Bstieler, 2005; Sainio et al., 2012). It determines how firms interpret and evaluate current market environments. As Weick (1988) suggests, turbulences in market conditions "defy interpretations and impose severe demands on sensemaking" (p. 305). On the one hand, firms may find it difficult to forecast demands as customer preferences are continuously evolving. Thus, highly unstable market conditions would cause firms to keep their status quo or become more risk averse (Chandrashekaran et al., 1999), even firms tend to scale back their innovation investment across the board (Bstieler, 2005). On the other hand, market uncertainty is also characterized by continuous changes in the composition of customers (Sainio et al., 2012), and firms tend to have new customers whose product needs are different from those of current customers. To avoid losing customers, firms must become innovative to respond to the changing preferences of current customers as well as the preferences of new customers. In summary, firms are caught in a dilemma
under high market turbulence.

To balance the benefits and costs of innovation under market uncertainty, continuous micro-innovation may be a potential option. Generally, developing inventions require a longer time frame and commitments (from idea to experimentation to commercialization) from a firm, making it more difficult for the firm to keep up with the pace of changing customer preferences. When market turbulence increases, many firms are likely to reduce their commitments to inventions as the cost may outweigh the benefits of doing so (Bstieler, 2005). Nonetheless, utility model patents involve a comparatively lower level of creativity and are less costly than inventions. Subject to preliminary examination, a utility model takes just several months to obtain, from filing to the grant of a patent right. Therefore, utility model protection is worthwhile for innovations that include minor technical improvements but are of considerable commercial value. Similarly, designs patents require less resources and time. Also, a design is an artistic creation featured by the decorative or aesthetic exterior appearance of an article, which can play a critical role in consumers' purchase decisions. Therefore, relative to inventions, designs may also be a very cost effective and powerful option that a firm can exploit to create and retain its competitive position in the marketplace.

Furthermore, continuously micro-innovation under a turbulent market environment requires more resources available within firms, and R&D subsidies can supplement this resource gap. Note that when market conditions are volatile, customers are more likely to demand for wide varieties of product options and to search information extensively for better price (Grewal and Tansuhaj, 2001), and customer demands become more complex and unpredictable as competition intensifies (Schuster and Holtbrügge, 2014). To survive in such market conditions, firms that have received R&D subsidies could use these additional resources to update their current products or change designs to suit relatively predictable market trends at little cost. Hence, rising challenges from competition along with uncertain demand patterns could enhance the efficacy of R&D subsidies on the creation of utility model and design patents rather than invention patents.

H3: Relative to invention patents, market uncertainty strengthen the positive effects of R&D subsidies on (a) utility model patents, and (b) design patents.

3. Data and methods

3.1. Samples and data

This study sets its context in China. As one of the fastest and largest growing economies in the world, the Chinese central and regional governments have been encouraging innovation and subsidizing R&D activities for many years as part of their central planning (Boeing, 2016). Additionally, firms in China have spurred significant innovations in the last two decades or so (Hong et al., 2016). Furthermore, consumer markets in China have become more massive and diversified, and firms must adapt to changing technological environments too. All of these suggest that China provides an appropriate setting to study the relationships among R&D subsidies, environmental forces, and innovations.

Consistent with prior research (Chen et al., 2018; Hong et al., 2016), this study focuses on high-tech industries because firms in these sectors file the most patents in China. Based on the OECD classification standards[6], high-tech industries consist of aviation and aircraft, biological medicine, electronics-communications, computer-related, instrument, and medical equipment manufacturing. Between 2009 and 2015, there were 469 high-tech firms publicly traded in the stock exchanges in China. Based on this sample of firms, we collected their firm level data, including R&D subsidies, firm characteristics, and financial measures, specific to our study from multiple databases. We also collected patent applications data from the State Intellectual Property Office (SIPO). We obtained R&D subsidies data from firms' annual reports and the Chinese databases WIND, Other variables are compiled from Chinese Stock Market Research (CSMAR) database[7]. After removing six firms with excessive missing data, our sample involved 463 firms or 2,611 firm-year observations across all years.

3.2. Model setting

To start, we set the benchmark model as follows:

$$Patent_{i,t+1} = \beta_0 + \beta_1 Subsidy_{it} + \sum \beta_k Z_{it} + \delta_t + \varepsilon_{it} \qquad (1)$$

where *Patent* is the number of patent applications; *Subsidy* represents R&D subsidies granted to a firm in a year; a vector of controls *Z* is included for each observation; *β* is the coefficient of a variable on *Patent*; δ and *ε* represent respectively a time-fixed effect and an error term; and *i* and *t* are subscripts corresponding to a specific firm and year.

3.3. Measures

Considering the important limitations of using only the aggregate number of patents as an indicator of firm innovation, we separate *invention patents* from *utility model patents* and *design patents* to represent three distinctive dependent variables. Three types of patent data are directly available in the SIPO database and each of them is measured by straight number counts (Doh and Kim, 2014).

R&D subsidies are indicated by the amount of cash awarded by the Chinese central or regional governments to a firm (Boeing, 2016; Chen et al., 2018). To measure this variable, we first hand-collected from our sampled firms' annual reports, which disclose the names and amounts of all governmental subsidies projects. We then followed Boeing (2016) and Chen et al. (2018) to use a set of key-words to separate R&D subsidies aimed at supporting firms' innovation projects from government subsidies for other policy objectives.[8] Finally, *R&D subsidies* are log-transformed to reduce skewness.

Following prior literature (Goerzen, 2007), we measure *technical turbulence* using patent data to derive the percentage change in patenting activity by industry. As discussed by Goerzen (2007), the percentage change in the number of patents in industry between periods t and t-1 is a signal of the rate of technological change experienced by firms in that industry. Algebraically, we define this proxy variable as:

$$\Delta P_{it-(t-1)} = \frac{NP_{it} - NP_{i(t-1)}}{(NP_{it} + NP_{i(t-1)})/2}$$

where NP_{it}, is the number of patents assigned to industry *i* in period *t*.

Similarly, we took the percentage change of the sales and general administrative expenses by industry to measure *market uncertainty*. Generally, industries with stable customer preferences are likely to spend less on advertising, promotions, and other marketing related programs.

Consistent with the literature, we included a set of control variables that have direct bearings on innovation. *Firm age* is measured by the number of years between the founding year and 2015. In general, firms that have established longer are likely to have better credits, increasing their access to external financing for innovation activities (Guo et al., 2018). *Leverage* is the ratio of total debt scaled by total assets and is adopted to control its impact on innovation (O'brien, 2003). *Return on assets* or *ROA* reflects a firm's past performance and is measured by dividing net incomes over total assets. *Ownership concentration* is calculated by the percentage of shares owned by the largest shareholders. Previous studies found that *concentrated ownership* encourages innovation activities within a firm (Choi et al., 2011). The literature shows that firms tend to spend more on innovation when *business growth* is strong (Chen et al., 2018). We therefore controlled it by using the growth rate of its main business income. In addition, we included *R&D intensity*, i.e., R&D expenses scaled by total sales, to control its effect on innovation (Hong et al., 2016). *Venture capital* is shown directly related to innovation (Chen et al., 2018). We created a binary variable with "1" for a firm supported by venture capital and "0" otherwise. The extent of a firm's *political ties* can affect its resource acquisition connected to product innovation (Fan et al., 2007; Zheng et al., 2015). To account for this possibility, we created a dummy variable with "1" for a firm's chairman or chief executive officer having political ties to the government, and "0" otherwise (Fan et al., 2007; Zheng et al., 2015). We also controlled for *non-R&D subsidies*. Some firms might have received grants and subsidies from government for activities other than R&D related and the literature has shown that non-R&D subsidies also affect innovation (Boeing, 2016). The data were hand-collected from firms' annual reports and were log-transformed to reduce skewness. Finally, to control for *year fixed effects*, we included a series of dummy variables.

[Insert Table 2 about here]

4. Results

Table 3 shows the descriptive statistics of our data and Table 4 summarizes our hypothesis testing results based on the negative binomial method. With respect to H1, our findings indicate that R&D subsidies positively influence inventions (Model 1: $\beta = .0599$, $p < .01$) and utility models (Model 5: $\beta = .0372$, $p < .01$) but not designs (Model 8: $\beta = .0125$, $p > .10$), supporting H1a and H1b respectively. Further, a chi-square test shows that the effect is stronger on inventions than that on utility models ($\chi^2 = 6.79$, p = .0092), suggesting that R&D subsidies add more value to invention patents, and H1c is supported.

[Insert Tables 2 and 3 about here]

To examine the interaction effects postulated in H2 and H3, we first mean-centered our main effect variables before entering their interaction terms to each of our main effect models. Our results indicate that technological turbulence strengthens the positive effect of R&D subsidies on inventions (Model 3: $\beta = 1.739$, $p < .01$) but not on utility models (Model 6: $\beta = -.337$, $p > .10$) and design patents (Model 9: $\beta = -.975$, $p > .10$), supporting H2. Likewise, consistent with our prediction in H3a, our findings show that in the presence of high market uncertainty, increased R&D subsidies lead to more utility models (Model 6: β = .00179, p < .05). However, our findings indicate that market turbulence does not strengthen the effects of R&D subsidies on design patents (Model 9: β = -.0022, p < .10), rejecting H3b. Figure 1 illustrates the significant interaction effects of R&D subsidies with technological turbulence on inventions (Panel A) and those with market uncertainty on utility models (Panel B) and design patent (Panel C).

[Insert Figure 1 about here]

4.1. Post-hoc analysis

To confirm our premise of the importance of distinguishing inventions from utility models and designs, we re-ran our models using the cumulative number of patent counts of all types as a dependent variable. Results in Model 11 show that the main effects of R&D subsidies (β= .0471, p < .01) on total patents are statistically significant. These results are comparable to those using invention patents (Model 2) or utility model patents (Model 5) as a dependent variable. However, when taking environmental forces into account, our results provide important insights as to when certain types of patents are affected by R&D subsidies. Specifically, we found that technological turbulence continues to serve as a moderator, strengthening the effects of R&D subsidies on total patents (Model 12: β = .888, p < .05). Nevertheless, the coupling role of market uncertainty no longer holds (Model 12: β= .000322, p > .10). While these results are comparable to those using inventions as a dependent variable, they are not coherent with the findings of the other two patent types. Overall, the post-hoc analysis provides evidence to our assertion and further indicates the drawback of applying the combined measure of all types of patents to represent innovation.

4.2. Robustness checks

We examine the robustness of our empirical findings in three ways and summarize our results in Table 5. First, we use the mean value of the number of patents in Period t and Period t_{+1} as a dependent variable. As expected, the results in Models 13-15 show that the coefficients of R&D subsidies on inventions and utility models are positive and statistically significant, whereas the coefficient of R&D subsidies on design patents is not. Moreover, the interaction effect of R&D subsides and technological turbulence on inventions is positive and significant; so is the interaction effect of RD subsides and market uncertainty on utility models. Overall, these results are comparable to those reported in Table 4.

[Insert Table 5 about here]

Second, as mentioned in the literature, SOEs (state-owned enterprises) differ from non-SOEs in many ways. For instance, relative to SOEs, non-SOEs have a more intense competitive environment, stricter loan approvals, and less government subsidies (Wallsten, 2000). Moreover, non-SOEs have a stronger willingness to invest in inventions to build long-term competitive advantage, and top management of SOEs is more akin to government officials, leading to short-sightedness and incremental innovation. Therefore, we replace the full sample with a subsample made up of non-SOEs to check the robustness. The results are reported in Models 16-18 and are substantially the same as those reported in Table 4 using the full sample.

Third, R&D subsidies are indeed a careful ex ante screening process, through which governments evaluate the innovation capacity and potential of subsidies applicants and sort good firms from bad. In doing so, one of the criticisms of the evaluation of R&D subsidies lies in the sample selection, i.e., the increased patents of a firm stems from its high innovation capacity rather than from government subsidies. To examine whether sample selection biases exist in our data, we re-ran our data using hackman selection model. The results are reported in Models 19-21 and are similar to those reported in Table 4.

Forth, another endogenous problem arises from some unobserved factors being included in the error term that might lead to a biased estimation. Therefore, we adopt the multiple instrumental variable method to address this concern. In choosing an instrumental variable, the literature suggests that while such variables must be correlated with the endogenous variable in a regression model, it should not be correlated with the error term of the regression (Cameron and Trivedi, 2009). Accordingly, we select the sum of R&D subsidies at the industry level and each sampled firm's home state's fiscal revenue growth rate as two instrumental variables appropriate to our study (Fisman and Svensson, 2007; Wallsten, 2000). Using two-stage least square (2SLS) regression to retest our model, results displayed in Models 22-24 in Table 5 are consistent with those reported in Table 4.

5. Discussion

5.1. Implications to theory

Our empirical evidence provides insight into undermining the long debate on whether government subsidies are good for innovation. We find in our study that the effects of R&D subsidies on each type of patent are not identical—R&D subsidies directly influence inventions and utility models but not designs. This specific result contributes to theory by showing the importance of separating invention and utility model patents from design patents. Furthermore, in our post-hoc analysis where we test the model using the total patent counts of all types as a dependent variable, R&D subsidies are positive and significant (β= .472, $p < .01$). We suspect that for those previous studies that find no effects of R&D subsidies on innovation (Guan and Yam, 2015; Szücs, 2018; Werfel and Jaffe, 2013), their samples might have included a larger number of design patents relative to the other two types, jeopardizing the true effect of R&D subsidy on pure technical innovation, i.e., inventions and utility models. Thus, investigating each type of patent, as seen in our study, offers a more comprehensive understanding of the role of R&D subsidies.

Moreover, the inclusion of environmental forces in our study improves our understanding on the boundary conditions of the R&D subsidies—innovation link. While some previous research has explored environmental factors (Bstieler, 2005), empirical evidence remains behind. The current study extends the literature by systematically testing the moderating effects of technological turbulence and market uncertainty. We found that the effects of R&D subsidies on inventions are stronger in the presence of high technological turbulence. This result complements previous research (Fernández et al., 2010), which found that firms can stay afloat in highly unstable technological conditions when they are more innovative. However, to help these firms bring inventions to fruition in times of high technological turbulence, R&D subsidies provide such an important source of financial input.

Furthermore, our findings support the interaction effect of market uncertainty and R&D subsidies on utility models and designs. Different from our expectation, however, negative effect is found on design patents. One plausible reason for this unexpected outcome is that design patents require no technical novelty and therefore much fewer resources are needed from firms to navigate external forces. Hence, it is understandable that R&D subsidies and their interactions with the two environmental forces on design patents are negatively correlated. As for inventions, we reason that technological breakthroughs, as seen in various cases (e.g., Apple's iPhones, Dyson's hand dryers), appear immune from market uncertainty. Indeed, many new inventions are developed regardless of market conditions. Overall, our study is the first considering the interaction effects of R&D subsidies and environmental factors on each type of patent, illustrating again the importance of separating them from each other.

5.2. Implications to practice and public policy

To managers and policymakers, our findings offer practical advice as well. Although R&D subsidies are financial resources added to a firm, the firm should use such extra resources with caution. While subsidies are grants from government and therefore are not required to pay back under normal circumstances, receiving firms are still obligated to report their outcomes to government agencies (Montmartin and Herrera, 2015). For example, "Innofound" is a government-subsidized program in China that funds firms on R&D. Local authorities could revoke the firms' eligibility for subsidies should they fail to abide by the rules or become unable to develop new technology or products within a certain timeframe.[9] Thus, we advise managers and their firms to invest more diligently on inventions and utility models if environmental forces are not a concern, and definitely utilize subsidies for inventions rather than utility models when technological turbulence is high and vice versa when market uncertainty is low.

To policymakers, our study confirms the direct and positive effects of R&D subsidies on inventions and utility models, and no effects on design patents, suggesting that R&D subsidies should distribute to firms that primarily emphasize technological advancements and breakthroughs rather than designs. Our findings also caution policymakers to pay attention to environmental forces when allotting R&D subsidies to firms as the impacts of technological turbulence and market uncertainty vary from patent type to patent type. Moreover, instead of using the total number of patent counts as the sole outcome variable to measure innovation, policymakers should understand the importance of separating inventions from utility models and designs. Doing so enables them to develop public policy that helps optimize the unique role of R&D subsidies in navigating different types of external environments for different innovation outcomes.

5.3. Limitations and future research direction

Despite the significant contributions made by the current study, it has some limitations that warrant further investigation. First, our measure of R&D subsidies is in aggregate and does not consider its diverse sources. However, R&D subsidies could come from government agencies at different administrative levels (e.g., national level vs. city level). For example, Zhou et al. (2020) examine the heterogeneity effects of government subsidies on firm radical and incremental innovation, but Zhou et al. (2020) do not distinguish between the different types of government subsidies. As we know, government subsidies encompass a wide range of subsidy programs, such as R&D subsidy and non-R&D subsidy, and their objectives are distinct from each other (Chen et al. 2018). For completeness, if data are available, future studies may extend our analysis by examining different sources of R&D subsidies to see whether national-level R&D subsidies create outcomes different from subsidies offered by other administrative levels.

Second, our study focuses on outcomes (i.e., patents) rather than processes. Some researchers argue that learning takes place in a firm and R&D subsidies as a government policy to incentivize the firm to be creative may change the firm's culture, strategy, and actions (Chapman and Hewitt-dundas, 2015). Future research could combine our approach with managerial perceptual and behavioral data to better gauge any changes in corporate policy or strategies as a result of R&D subsidies.

Third, this study examines only two contextual factors, i.e., technological turbulence and market uncertainty. As institutional environments are increasingly unstable within and outside a firm's regime, particularly in emerging economies, future research could extend the resource dependence theory by studying institutional uncertainty and by comparing how R&D subsidies are affected in managing various types of external forces.

Fourth, although we have made extensive efforts to demonstrate the robustness of our findings, unobservable endogeneity bias may still exist, affecting our identification strategy. Ideally, our study would benefit from having panel data with a difference-in-difference (DiD) estimator (Szücs, 2018). Unfortunately, our current dataset has constrained us from so doing. To use DiD, we would need to have a control group. In our case, it would be firms that had never received R&D subsidies during the seven-year observation period. However, most of the publicly traded high-tech firms in our sample received R&D subsidies from government at some point in time. Future research could consider using data from other industries or other countries where a control group could be easily identified to re-examine our model. Using data from other sectors and countries further enables one to compare the effectiveness of R&D subsidies in helping firms manage environmental challenges.

In conclusion, our findings can be used to understand why R&D subsidies are not as useful as they are intended for innovations. This study shows that R&D subsidies and their impacts on innovations are a dynamic process that is affected by technological turbulence and market uncertainty, and the types of patents being investigated. To the extent that a firm can obtain R&D subsidies, more invention and utility model patents can result, but different environmental forces can shape and reshape these outcomes.

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[8] Following Chen et al. (2018), a project is considered R&D subsidized if any of the words below appears in the project's title: "research", "development", "technology", "innovation", "patent", "intellectual property", "technology standard", "technical transformation", "new product", "industry upgrade", "High-tech human resources subsidy", "laboratory construction subsidy", "spore", "enzyme", "injection", "capsule", "antibiotics", "plastics project", "new antitumor drug", "new anticoagulant drug", "sugar patent", governmental science and technology programs such as "863", "973", "Torch program", "Spark program" and local science and technology support programs.

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