The Effect of Patent Expiration on Pharmaceutical Firms' Research and Development Decisions

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Honors Thesis

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Abstract

How does the expiration of a pharmaceutical firms' drug patent affect the firms' R&D decisions? We attempt to answer this question by combining data from the FDA Orange Book dataset on drug patents with firm-level data from the Pharmaprojects database. We utilize a logistic probability model to determine how patent expiration affects the chances that a firm will undertake certain actions to mitigate the negative effects that patent expirations have on revenue streams. In doing so, we find that firms that are nearing patent expiration begin testing of new products and seek new licensing opportunities for existing products, rather than discontinue existing products.

Keywords: Patent Expiration, R&D Investments, Drug Development, Product Shocks, Biopharmaceutical Industry, FDA

1 Introduction

The process by which pharmaceutical firms develop new products is complex, expensive, and sensitive to external influences. Given the high costs and risks associated with research and development (R&D), the ways in which pharmaceutical firms craft their investment decisions are of utmost importance. This process has resoundingly positive effects on society. For instance, when looking at improvements in human health created between 1932 and 1982, Fuchs (1982)(2) finds that most improvements stem from R&D's ability to produce new drugs. More recent research suggests that the overall gains to society from pharmaceutical R&D are large (Lichtenberg, 2001, 2004, 2007)(7; 8; 10; 9). Moreover, due to the costs and risks associated with pharmaceutical R&D, patent protections are critical in promoting new R&D because they ensure firms the exclusive right to develop and sell a product (Sachs 2018)(11). However, it is imperative that patents do not provide too much protection, as this could result in a decrease in innovation by discouraging firms from taking on risks associated with R&D. As such, there is a clear link between balancing the incentives that patents provide to pharmaceutical firms and the benefits reaped from innovation.

Thus, the present study seeks to measure the effect that patent expirations have on R&D portfolios of pharmaceutical firms. We do this by utilizing a logistic probability model, regressing various actions that a pharmaceutical firm might take (developing a new product, launching a product in different countries, etc.) on a window of time surrounding the expiration of one of the firms' patents. We conduct these analyses using public FDA Orange Book patent data in addition to firm-level data

obtained from the Pharmaprojects database.

Although firms know ahead of time when patents expire, we take patent expirations to be exogenous since firms cannot control how long patents last and when they expire, as patent laws are set by the Federal Government. Additionally, firms are incentivized to file patents on new drugs as soon as possible to ensure that their idea is protected by the exclusivity that a patent provides. Thus, since firms can control when they apply for a patent, but not when it expires, and firms file patents as soon as possible to protect their ideas, not to choose a specific expiration date, we are able to take the date of patent expiration as an exogenous variable. This allows us to extract a causal relationship between patent expiration and firms' R&D decisions. Unlike patent expiration, firms' responses, however, are endogenous since firms actively decide what actions to take and when to take them.

While numerous papers have explored how firms make R&D decisions, many have focused on how these decisions are made in response to exogenous shocks, such as policy decisions or the successes and failures of other drugs. For example, Krieger, Li, and Thakor (2018)(4) find that FDA public health advisories drastically increase the likelihood that firms acquire R&D from other firms, rather than conducting their own in-house trials. Similarly, Krieger (2016)(Krieger) finds that pharmaceutical firms often pare back their R&D investments in response to news of a competitor's failure. However, there has been little research into how other factors, such as patent expiration, affect firms' R&D decisions. Although patent expirations are similar to the aforementioned shocks, there is a key difference between them. When firms file a patent, they are aware of when it expires. Thus, firms can plan ahead and take

measures to prevent negative outcomes associated with patent expirations, such as the negative impact to revenue streams resulting from the loss of exclusivity. This is not the case for shocks like Public Health Advisories, which are assumed to be a surprise to firms.

Based on standard economic theory, if a firm realizes that they are going to lose a profitable revenue stream to patent expiration, they will likely take measures to either extend the patent, create new in-house R&D, or attempt to acquire profitable R&D from an outside source. The specific strategy that a firm employs is highly dependent on their previous experiences in the market. For example, a firm that had previously unsuccessfully attempted to enter the market for cancer treatment drugs may instead opt to develop a drug to treat diabetes, given their previous failure. Furthermore, if a firm has a successful patent, they may try to gain more market share by developing a new way to administer the drug, extending the duration of the patent, and by acquiring complementary R&D from another firm. The timing of a firm's actions is also imperative. Since R&D is conducted over long periods of time, a forward-looking firm that begins developing a strategy before nearing patent expiration will likely be more successful than a myopic firm that only begins innovating after their patent expires. The present study seeks to explore if patent expiration affects the way that firms act and how this aligns with what we expect.

This paper explores the firms' decision-making processes both before and after the expiration of one of their patents. For example, if a pharmaceutical firm knows that the patent for one of their major products is nearing expiration, does that firm attempt to increase in-house R&D to extend the existing patent, explore R&D

options to develop a completely new product, attempt to acquire R&D from another firm, or do they do something completely different? In our analyses, we attempt to leverage the stage of R&D, market targeted by R&D, geographical location of the firm, and the type of patent to determine what actions different firms take in response to the loss of patent exclusivity.

The paper proceeds as such: we provide a literature review in section 2. Then section 3 details the data we use. Section 4 explains the empirical model. Section 5 provides results and section 6 concludes.

2 Literature Review

There has been significant research on internal capital markets that seeks to discover how shocks to firms' products affect investment across different products (Stein, 1997; Lamont 1997; Shin and Stulz, 1998; Scharfstein and Stein, 2000; Bertrand and Mullainathan, 2005)(Stein; 13; 12; 1). For example, Lamont (1997)(6) finds that when oil prices fall, oil companies significantly decrease their investment in their non-oil subsidiaries. This suggests that the negative shock, a decrease in oil prices, affects the firm in ways that perhaps were not expected.

While this paper is related to existing research on internal capital markets, it differs in that much of this existing research is related to industries, such as energy and transportation, that require significant physical capital. In contrast, pharmaceutical firms do not rely as heavily on physical capital, and instead face significant uncertainty in the development of their drug portfolios. The lesser reliance on physical

capital and heightened uncertainty may result in pharmaceutical firms taking vastly different actions when faced with a shock. For example, if demand for a pharmaceutical firm's primary drug suddenly falls, they may decide to quickly pivot and alter their drug portfolio by acquiring the rights to market a different drug, whereas an energy firm may not be able to make such a pivot given the high cost of physical capital in this industry.

Additionally, pharmaceutical firms make decisions not only between different products, but also along the whole development period of individual products (Krieger et al., 2018)(4), unlike decisions made in the internal capital markets literature. This can be seen through the long, arduous process of drug approval, which requires a series of three human trails, each of which is more stringent than the last. Throughout this process, the pharmaceutical firm must make decisions about an individual drug that can ultimately determine whether it gets approved to be marketed. For these reasons, Krieger et al. find that while research in capital markets suggests that firms pare back investment after shocks, pharmaceutical firms increase R&D when faced with uncertainty.

Krieger et al. (2018)(4) utilize FDA Public Health Advisories (PHAs) as a shock to pharmaceutical firms' pipelines, and then examine how the firms change their drug portfolios in response. Using a difference-in-difference approach, they find that firms that experience a PHA respond quickly, with a 21% increase of R&D expenditure, often in the form of R&D acquisition from other firms. We complement research conducted by Krieger et al. by examining the effect of patent expiration on R&D decisions, rather than the effect of FDA Public Health Advisories on R&D decisions.

Other research related to the current paper includes Krieger (2017)(3) in which he analyzes the effect that failure of firms in the pharmaceutical industry has on the decision of competitors to discontinue similar R&D. He uses a difference-in-difference approach to find that firms are most sensitive to the failure of other firms that are in the same market and technology area.

Furthermore, Krieger suggests that firms often overreact to failures reported by very closely related firms. Krieger's research addresses these spillover effects and allows for differences in the ways in which firms interpret the failure of a competitor. He finds that firms do, in fact, use news of a competitor's failure to influence their own investment decisions, specifically when the competitor is situated in the same market and technology space. He also finds that information shocks from a firm's closest competitor do, in fact, result in the overreaction of a firm by means of paring back their own R&D.

Although this is related to the current paper in that it analyzes the effects of an unexpected shock (failure of a competitor's drug) on a firm, it differs in that the shock and subsequent reaction are experienced by two different firms. Instead of examining spillover effects that a failure of a drug has on other firms, we specifically look at how a firm reacts to the expiration of one of its own drug patents, rather than how one firm's patent expiration might affect another firm.

3 Data

3.1 FDA Orange Book

The data for this study comes from two different sources, the first of which is the FDA's Orange Book database. The Orange Book is a list of United States patents for drugs that have been tested and approved for use in United States the by the FDA. The patent data that we use from this dataset ranges from 1990-2014. In addition to patent number and the edition(s) of the Orange Book in which patents are included, the dataset also includes patent expiration dates for each patent number, and indicator variables to denote whether the patent has a drug substance (DS) claim, a drug product (DP) claim, or both.

If DS is 1, then the patent was a drug substance claim, if DP is 1, then it is a drug product claim, and vice versa. These two types of patents are fundamentally different, but not mutually exclusive, meaning that a drug can have both a DS and DP claim. While a DS claim protects the active ingredient of a drug, a DP claim protects the delivery method of the substance. For example, a patent on a drug that treats diabetes may have a DS claim on gliclazide, the active ingredient, and also a DP claim on the tablet form that it comes in. Therefore, the type of patent may have an effect on how pharmaceutical firms react to its expiration.

3.2 Pharmaprojects

Our firm-level data comes from the Pharmaprojects database, which includes data for pharmaceutical firms throughout the world, their drug portfolios, and "key

events" for specific drugs. These key events are actions that firms may take in response to patent expiration. For example, one event that a firm may undertake is "new product", meaning that the firm has a product that is starting to undergo clinical trials. Since these events are not mutually exclusive, and firms may have multiple drugs in their portfolio, a single firm may undertake several of these actions at once or over a period of time. The full list of key events and their relative frequencies is provided below.

Table 1: Key Events with Relative Frequencies

Key Event	Frequency	Percent
New Product	45,073	24.51
No Development Reported	39,871	21.68
Change in Global Status	11,555	6.28
Licensing Opportunities	10,537	5.73
Discontinued Products	8,674	4.72
Development Continuing	7,953	4.32
New Disease	6,988	3.80
New Licensees	6,659	3.62
Additional Launches	5,869	3.19
New Chemical Structure	5,859	3.19
Additional Registrations	4,36	2.37
New Therapeutic Activity	3,988	2.17
Compounds Identified	2,758	1.50
Orphan Drug Status Granted	2,672	1.45
Licences Discontinued	2,207	1.20
New Patent Applications	2,056	1.12
Patent Expiration	1,996	1.09
Names Granted	1,897	1.03
Mechanism Identified	1,736	0.94
First Launches	1,732	0.94
Suspended Products	1,669	0.91
Registration Submissions	1,502	0.82
Change in Disease Status	1,480	0.80
First Registrations	1,480	0.80
Target Identified	1,235	0.67
Change in Licensee Status	959	0.52
Novel Target Reported	548	0.30
Global Status Reversion	326	0.18
Withdrawn Products	246	0.13

We use these as the outcome variables in our analyses to find what actions firms are taking near the time of patent expiration. Of the events listed above, we choose to run our regressions on 10 of the most frequent, namely, new product, additional launches, new patent application, first launches, change in global status, licensing opportunity, new licensees, orphan drug status granted, product discontinued, and licenses discontinued. By exploring which of these events firms undertake near the time of patent expiration, we can get a sense of what types of actions firms take to mitigate the negative effects of patent expiration.

We utilize Pharmaprojects data from 1990 through 2015. The variables that we use in our analyses include the name of the pharmaceutical firm, the name of their drug(s), the diseases that the drug is used to treat, information about the firm's location, and a list of key events that the firm has undertaken on corresponding "key event dates".

3.3 Summary Statistics

The data is organized by year and by quarter within each year. We use quarterly data from 1990 through 2014. We include figures detailing the change in number of several of the most frequent and salient, as they relate to our analyses, key events over time. These include new product, licensing opportunities, and discontinued products.

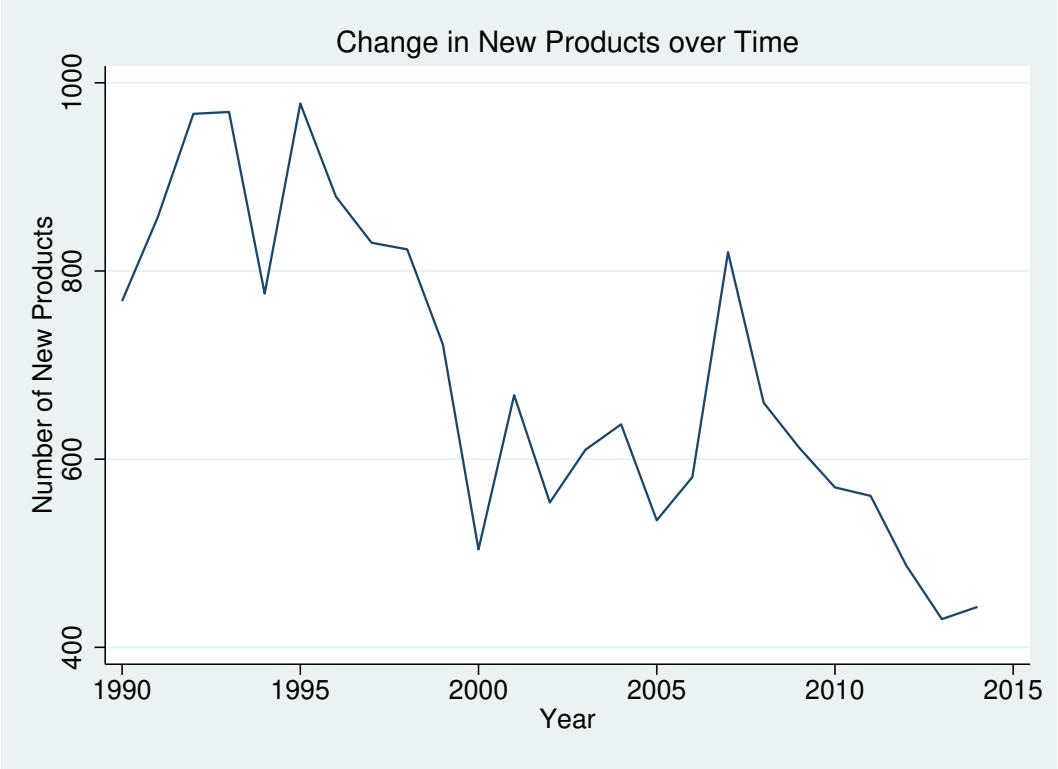

Figure 1

Figure 1 shows the change in number of new products over time. Although the number of new products seems to fluctuate from year to year, we note that it never falls below 400. This suggests that while the number of new products that a firm develops may vary from year to year, developing new products seems to be one main way in which firms attempt to grow their drug portfolios and their revenues. In addition, Figure 2 shows the number of licensing opportunities the firms in our sample possess over time. Similarly to new products, licensing opportunities appear to fluctuate throughout our sample period. Nevertheless, they remain one of the most common ways for firms to adjust their drug portfolios.

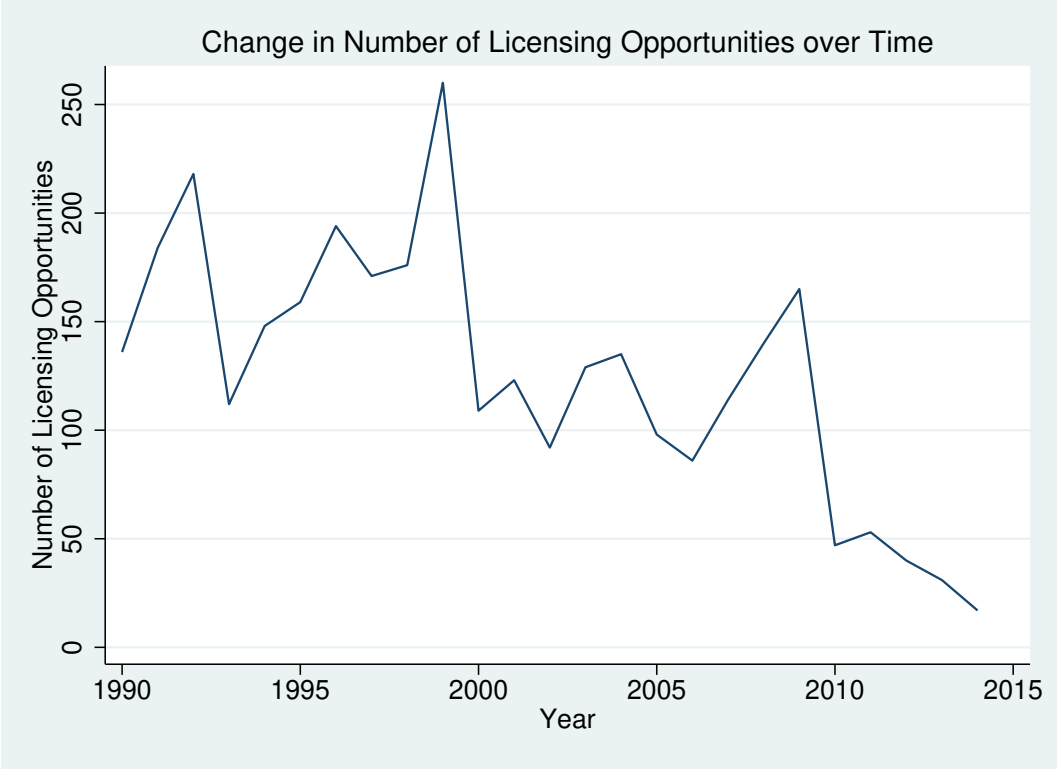

Figure 2

In addition to new products and licensing opportunities, we also include Figure 3, which gives a sense of how the number of discontinued products changes over our sample period. We note that the number of discontinued products dramatically decreases from 1990 through 2015. While the changes between 1990 and 2010 may just be the result of changes in firm behavior, the decline in new products, licensing opportunities, and discontinued products after 2010 may be related to Figure 4, which shows the change in the number of firms in our sample. This figure suggests that the number of firms in our sample each year fluctuates, and decreases significantly after 2010. Since there are fewer firms in our sample after 2010, this is likely why we see

fewer actions being taken in these years.

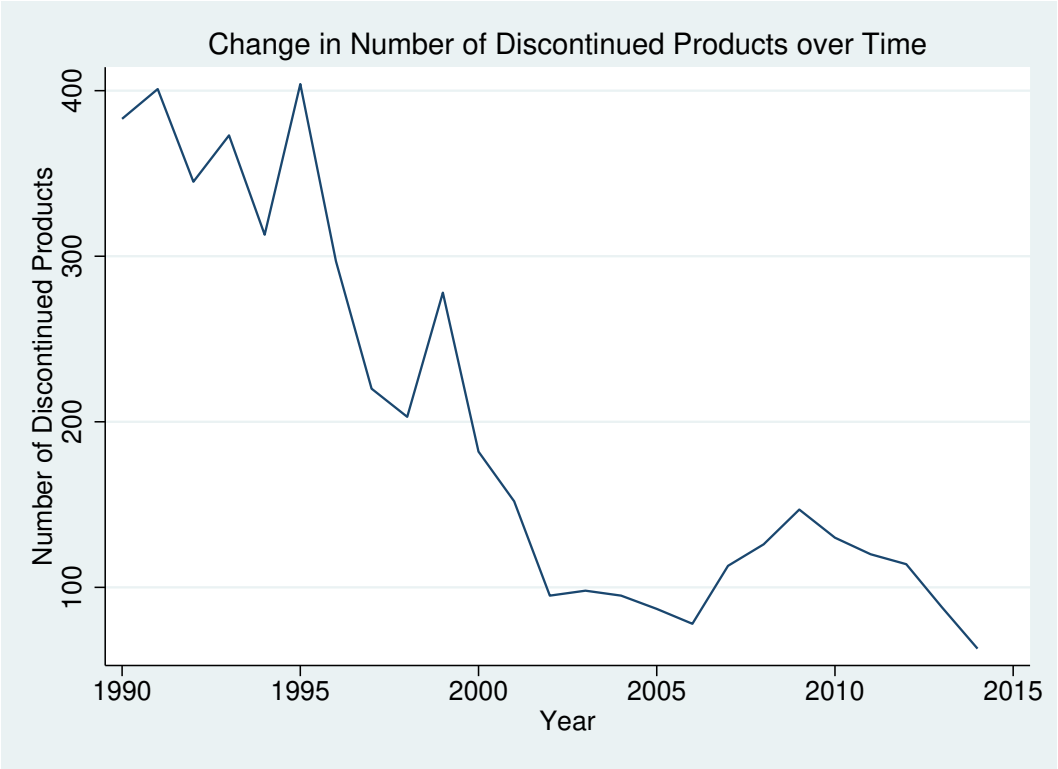

Figure 3

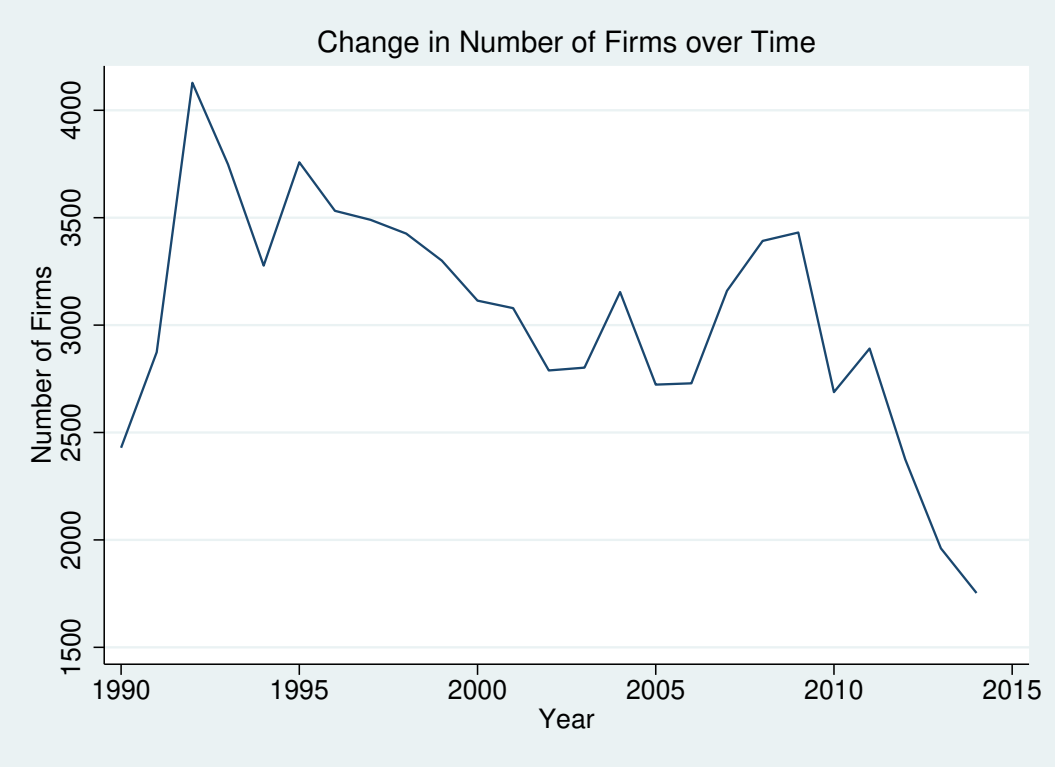

Figure 4

We next document the number of patent expirations per year in addition to summary statistics for the number of patent expirations per firm over the whole sample. The average number of expirations per firm is 8.717, with a standard deviation of 15.432. Since we only included firms with at least one patent expiration in our sample, the minimum is 1 and the maximum is 93. The large standard deviation in patent expirations makes sense since some larger firms will have larger drug portfolios, more patents, and more patent expirations. The large increase in the number of patent expirations over time in Figure 5 is likely related to two things, namely, the growth of the pharmaceutical industry in the United States and the practice of

having multiple patents for different aspects of the same product.

Variable	Mean	Std. Dev.	Min	Max
Patent Expirations	8.717	15.432	1	93

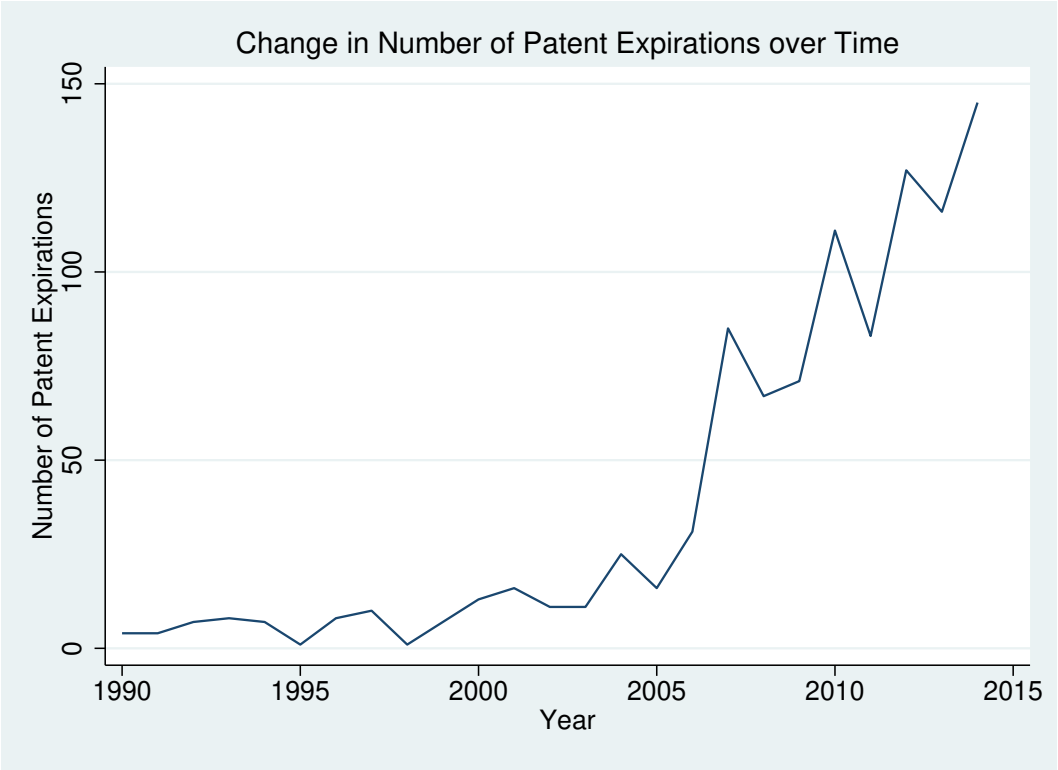

Figure 5

3.4 Background

After a pharmaceutical firm's patent expires, and they lose exclusivity, the drug becomes part of public domain, and the market for the drug generally becomes saturated with generic version of the drug, driving down prices and therefore profits for

all firms in the market. Determining the length of this period of exclusivity, however, is a difficult task. Lawmakers must grant enough exclusivity to promote innovation of novel drugs by pharmaceutical firms, while not granting so much exclusivity that the firm no longer has an incentive to produce new innovations. The current state of patent expiration laws dictate that the majority of patent types expire 20 years after the application for the patent is filed. However, there are ways to extend an existing drug patent, such as making developments on the existing drug.

While the opportunity to extend an existing patent may encourage some pharmaceutical firms to continue developing newer and better version of their drugs, this can also be taken advantage of. For example, a firm can change the delivery method of the drug from an injection to a capsule, and be granted an extension of their exclusivity over the drug. The existing system of issuing 20 year patents with opportunities for exclusivity extensions may encourage innovation, or it may stifle innovation by allowing firms to simply make small changes to existing drugs. Given that a goal of the system is to promote innovation of novel drugs, and that the effects of patents and their expiration on the whole are hard to measure, it is important that we analyze how these firms act when nearing the end of one of their drug patents.

4 Empirical Model

To identify the impact that patent expiration has on a firms' R&D decisions, the current study builds upon the empirical model in Krieger et al(4). While Krieger et al. utilizes a difference-in-difference model to explain how FDA Public Health

Advisories affect various outcome variables including R&D, earnings, cash, and debt, we employ a logistic probability model with time and firm fixed effects that allows us to predict how patent expiration affects the probability that a firm will undertake some of the most frequent key events listed in section 3.2 in order to mitigate losses associated with patent expiration. Also, we only include firms that have experienced at least one patent expiration in our sample. By excluding firms that have no patent expirations, but may have undertaken events, we reduce the bias of our estimators in order to obtain a more causal relationship between patent expiration and our event variable.

Of the 29 events in the original dataset, we run regressions on new product, additional launches, new patent application, first launches, product discontinued, licenses discontinued, change in global status, licensing opportunity, new licensees, and orphan status granted. We selected these based on how frequently they occur as well as how salient they are in addressing the question of how patent expiration affects a firms' actions. For example, we choose to omit names granted and withdrawn products, since names granted does not indicate a change on the part of the firm and withdrawn products occurs only 246 times.

We utilize the model:

$$Event_{i,t} = \alpha + \beta Exp_{i,t-3 \text{ to } t+.5} + \gamma Controls_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \tag{1}$$

Where Event takes a value of 1 if firm i undertook the specific action in time t and 0 otherwise. Likewise, $\beta Exp_{i,t-3 \text{ to } t+.5}$ takes a value of 1 if firm i experienced a patent expiration during the years t-3 and t+.5. In doing so, we create an asymmetric

window of three years prior to and six months after patent expiration, which allows us to identify which actions a firm is taking in response to a specific patent expiration. Additionally, we add firm and time fixed effects, μ and λ. We include these fixed effects because we expect that there are some variables that we are not able to control for, like firm size, that could bias our estimators. For example, larger firms may take more actions, meaning that, without controlling for firm size, we may overestimate the effect that patent expiration has on firms' actions. Thus, these fixed effects are useful in controlling for heterogeneity between firms and trends that affect the R&D of all firms over time.

In addition to analyzing the behavior of firms throughout the entire window, we also utilize a second model by which we regress each of the 10 events on three, two, and one year(s) before and six months after after patent expiration to determine if firms take action in a specific year near patent expiration, or if their activity is more continuous throughout the entire window. In doing so, we utilize an equation similar to equation (1), but with separate terms for each year:

$$Event_{i,t} = \alpha + \beta_1 Exp_{i,t-3} + \beta_2 Exp_{i,t-2} + \beta_3 Exp_{i,t-1} + \beta_4 Exp_{i,t+.5} + \gamma Controls_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \tag{2}$$

In order to analyze the effect of public health advisories on their output variables of choice, Krieger et al. (2018)(4) utilize a window of t-3 to t years before the public health advisory was issued. Similarly, our model examines the effect of patent expiration on firm's R&D decisions. Since utility patents generally last for 20 years (with some of them expiring sooner and some being extended past 20 years), we

analyze firms' actions within the window of time three years before and six months after a patent expires. This allows us to capture the effects of patent expiration both before and after the expiration occurs. We do not want to make the window too wide, for fear of capturing actions being taken by a firm that are unrelated to the expiration of one of their patents. This could result in biased estimators, which would take away from the predictive power of our estimates. Additionally, since the probability that a firm is taking actions regarding their drug portfolio decreases as we move further out from the date of expiration, we expect that there will be a large number of years when no key events are reported, and some years (closer to the date of the patent expiration) when the firms may undertake several actions.

5 Results

Our analyses employ a logistic probability model to predict the effect that a patent expiration has on pharmaceutical firms' R&D decisions. We regress each of the actions outlined in section 4 on both our entire window, and the window broken down by year, as in equations (1) and (2). This allows us to discern how the knowledge of a patent expiration changes the probability that a firm will undergo each of the actions. The tables below group the actions into three categories based on when in the drug development process they most often occur: initiation, intermediate, and termination. To fit each event into a category, we sort our data by firm, drug, and date, then count the number of times that each event appears at the beginning, middle, and end of the development process of each drug. We are then able to

sort the events into each of the categories based on how frequently each occurs at each point in the development process. In doing so, we find that new product, new patent application, and first launches are initiation events. Change in global status, licensing opportunities, new licensees, additional launches, and orphan drug status granted are intermediate events. While discontinued product and discontinued licenses are termination events. This allows us to to split up the presentation of our results into 3 sections, one for each category.

The tables below contain 5 columns. The first 4 are the results from equation (2) in section 4, where we regress each event on 3, 2, and 1 year before patent expiration and 6 months after patent expiration. Column 5 comes from equation (1) in section 4, and shows the effect of patent expiration throughout the entire window on each event. The estimates in all of the tables are marginal effects, and as such can be interpreted as how much more or less likely a firm is to undergo each of the actions, given that they experience a patent expiration.

5.1 Initiation Events

Table 2: Logit Model for Effect of Patent Expiration on Various Initiation Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+.5	t-3 to t+.5
Panel A: Initiation Events					
New Product	.031*	.046**	.006	-.007	.033**
	(.019)	(.020)	(.019)	(.020)	(.033)
New Patent Application	.032	.025	-.027	.003	.063**
	(.035)	(.036)	(.026)	(.031)	(.029)
First Launches	.006	-.001	.010	-.011	.005
	(.011)	(.011)	(.012)	(.010)	(.008)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

First, we examine the effect of patent expiration on 3 initiation events. We find that, throughout the entire window extending three years before to six months after patent expiration, firms are slightly more likely to undertake an initiation action given the knowledge that one of their patents is expiring. For example, firms are .5% more likely to attempt first launches, and 3.3% more likely to have a new product enter the testing phase, which is statistically significant at the 95% level. Additionally, firms are 6.3% more likely to submit a new patent application during this window, which is also statistically significant at the 95% level. Looking at columns 1 through

4, we find that two years before patent expiration is the period in which a firm is most likely to have a new product enter testing.

The statistically significant, positive coefficients on new product and new patent application are somewhat surprising. A product that has recently entered testing is roughly a decade away from its release to the public, and the issuance of a new patent application represents a drug that is likely even further from release. This means that the new products that the firm is creating and the patent applications that the firm is submitting will not result in a source of revenue by the time their patent expires. Given the limitations associated with the length of our window, as discussed in section 4, we only observe actions up to three years before patent expiration. As such, we do not expect these to be the primary ways in which firms mitigate the loss of revenue associated with patent expiration in the window of time we examine. Instead, these are longer-term solutions that may yield payoffs in the years following patent expiration.

Instead of releasing new products to testing and submitting new patent applications, we expect that the initiation event that a firm experiencing impending patent expiration is most likely to implement is the first launch of a drug that has been approved to be released by the FDA. Our results, however, indicate otherwise. We find that first launches are not an avenue that firms seem to be utilizing in order to make up for revenues lost by patent expiration. While the coefficient on first launches in column 5 is positive, it is small and statistically insignificant. This, too is surprising, since launching a new product is a potential way to quickly create new revenue streams.

A possible explanation for these results are that firms are simply taking initiation actions later than we expected, suggesting that they do not act in this way to quickly make up for revenues that they lose from patent expiration. Instead, they may take a mixture of initiation and intermediate actions that both mitigate the short-term losses in revenue associated with patent expiration, in addition to building their drug portfolio in the long-run. Alternatively, these findings may also be linked to limitations of our window selection. In this way, we could be detecting actions in year t that a firm undertakes to mitigate losses of revenue associated with a patent expiration in year t+10, for example. However, the former explanation is preferable since we take patent expiration to be exogenous. Since firms are profit maximizing and tend to prioritize current profits over future profits, we argue that, firms likely do not decide when to file a patent based on the date that it will expire, but instead file it as soon as they can to protect their intellectual property. In addition, once a patent is filed, patent laws, not firms, decide when patents expire. Thus, we take patent expirations to be exogenous, suggesting that firms undertake a mix of short and long-term solutions to solve the problem of patent expiration.

5.2 Intermediate Events

In addition to analyzing the effect that patent expiration has on the probability of a firm undertaking an initiation event, we also examine the effect that it has on intermediate events.

Table 3: Logit Model for Effect of Patent Expiration on Various Intermediate Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+.5	t-3 to t+.5
Panel B: Intermediate Events					
Additional Launches	-.017	.019	.012	-.011	.003
	(.014)	(.017)	(.018)	(.017)	(.012)
Change in Global Status	.011	-.008	-.006	-.013	.001
	(.017)	(.016)	(.017)	(.017)	(.012)
Licensing Opportunity	.016	.025	.024	.001	.022*
	(.016)	(.018)	(.018)	(.017)	(.022)
New Licensees	.024	-.001	.025	.038**	.036***
	(.016)	(.015)	(.018)	(.019)	(.012)
Orphan Drug Status Granted	-.009	-.006	.020	-.005	.000
	(.014)	(.015)	(.018)	(.016)	(.012)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The above table displays regression results from five different intermediate actions, with columns 1 through 4 again representing equation (2) and column 5 representing equation (1). One striking result is that from t-3 to t+1, firms that experience patent expiration are 3.6% more likely to find new licensees, which is significant at the 99% level, and 2.2% more likely to seek licensing opportunities, which is significant at the 90% level. The positive signs on these values may suggest that some firms attempt to license their drugs to other distributors in order to attract a wider audience and market their drug to more people. Thus, a pharmaceutical company may seek to replace lost revenue streams associated with patent expiration by seeking new licensees to promote existing drugs, rather than by attempting additional launches or marketing these drugs globally.

This finding is in line with observations from the initiation events results. What we see is that firms are more likely to undertake actions that will have payoffs long after patent expiration, in addition to undertaking actions that have more immediate payoffs. The long-term actions, as discussed above, are new product and new patent application, while the short-term actions are licensing opportunities and new licensees. So, what we see is that firms that have patents expiring are more likely to attempt to mitigate losses in revenue in the short-term by licensing existing products, while at the same time developing new drugs that can later replace the product for which a patent is expiring.

5.3 Discontinuation Events

Lastly, we analyze the effect that patent expiration has on the discontinuation of products and licenses. Similarly to our other two analyses, columns 1 through 4 represent results from equation (2) of section 4, whereas column 5 represents results from equation (1) of section 4.

Table 4: Logit Model for Effect of Patent Expiration on Various Termination Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+.5	t-3 to t+.5
Panel C: Termination Events					
Product Discontinued	-.010	.019	.006	-.011	.001
	(.015)	(.018)	(.017)	(.016)	(.011)
Licences Discontinued	.029	-.001	.007	.018	.021*
	(.019)	(.015)	(.017)	(.020)	(.012)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

We find that three, two, and one year prior to patent expiration, six months after patent expiration, and throughout the entirety of this window, firms largely do not seem to react to patent expiration by discontinuing existing products. This is somewhat surprising, since discontinuing a product should reduce a firm's revenue, thus creating a larger burden on the firm. So, we would expect the coefficient on

product discontinued to be negative, since this would suggest that firms are less likely to discontinue a product in the years leading up to patent expiration, and would instead attempt to find additional sources of revenue. However, we find that firms do not seem to react along this dimension.

There is, however, a sizeable effect on discontinuing licenses that is statistically significant at the 90% level. Firms that experience patent expiration are 2.9% more likely to discontinue a license three years before patent expiration and 2.1% more likely to do so throughout the entirety of the window. This is surprising, since in Table 3 we see that firms are more likely to seek and obtain new licenses. This may signal that near patent expiration, firms both discontinue licenses for drugs that are near patent expiration while simultaneously searching for new licenses on existing drugs to make up for this loss of revenue. This, as we discussed before, might mean that firms take multiple actions to mitigate negative effects of patent expiration by, for example, releasing a new product to testing, finding new licensees for existing products, and discontinuing licenses for old products. Aside from these estimators, however, many of the individual year estimators have relatively small and insignificant values, meaning that we cannot confidently say that they are different from zero.

5.4 Robustness

For robustness, we change both the length of the window around patent expiration that we use in our regression as well as the range of dates that we utilize in our model. By changing the window that we observe around the time of patent expiration, we

check to see if three years prior to and six months after patent expiration is sufficient to examine actions taken by firms. Although the results do not materially change when expanding the window by one or two years, there is a risk that by expanding the window any more, some firms will always be included as "facing patent expiration", which could skew results. For example, by extending the window to include ten years before patent expiration and six months after, nearly all of the events gain a positive coefficient that is statistically significant, in most cases, at the 90% level or higher. By extending the window to ten years prior to patent expiration, the majority of years become "patent expiration" years, meaning that almost every action that firms take is attributed to a patent expiration. Thus, by utilizing the window of three years before to 6 months after patent expiration, we may be underestimating the effect of patent expiration on firms' R&D decisions. In addition to adjusting the window, we also restrict the range of dates that we use in our analyses, which results in largely the same results. Lastly, we also utilize a linear probability model to test the robustness of the logistic probability model and find that results do not materially change when employing the linear probability model. Overall, the main results hold after extending the event window to four and five years prior to expiration in addition to changing the range of included dates.

6 Conclusion

This paper evaluates the effect that patent expiration has on pharmaceutical firms' R&D decisions. Using both FDA patent data from the FDA Orange Book,

and private firm-level data from the Pharmaprojects database, we analyze what actions these firms take when facing the negative effects of patent expiration. We find that in the window of time three years prior to and six months after patent expiration, pharmaceutical firms that face patent expiration seem to be more likely to start trials on new products, submit new patent applications, seek new licensing opportunities, and discontinue old licenses. This evidence is somewhat consistent with our expectations, with two main exceptions. First, in addition to taking actions to immediately increase revenues, firms also undertake longer-term actions that have the possibility of yielding revenue after patent expiration. Second, firms that experience patent expiration are not less likely to discontinue products in the years leading up to the expiration. Overall, our findings support anecdotal evidence that finds that firm managers often take whatever actions they find necessary to make up for the revenue lost when a patent expires, which sometimes includes both initiation and intermediate events.

These findings are relevant to prior literature on internal capital markets in addition to related research on how pharmaceutical firms react to negative shocks, including Public Health Advisories and the failure of adjacent firms. Much of this past literature finds that these negative shocks are linked to an increase of R&D expenditure by pharmaceutical firms, something that the current study corroborates. We also conduct robustness checks in the form of changing the window of time around patent expiration that we use in our regressions as well as shortening the range of dates we include. Overall, these changes yield results similar to our main analyses.

In addition to being relevant to prior literature on the effects of shocks to firms,

this research is also relevant to the formation of patent laws in the United States. Since one goal of the patent system is to maximize innovation, it is crucial that we evaluate how the current system achieves this goal. For example, we find that the negative effects of a patent expiration spur firms to file new patent applications and seek new licensing opportunities. As such, this may suggest that the current system motivates firms to innovate and produce novel drugs. While this finding may be relevant to policy makers insofar that it may be used to motivate future changes to the current US patent system, there is still a large gap in the literature on how patent expirations affect pharmaceutical firms' R&D decisions that should be bridged before we reach a consensus on this subject.

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7 Appendix

Below is a table showing the effect of patent expiration on the key events we did not include in the main analyses.

Table 5: Logit Model for Effect of Patent Expiration on Various Events Not Included in Main Analyses

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+.5	t-3 to t+.5
Appendix Regressions					
No Development Reported	-.020	.052**	-.005	.034	.034**
	(.018)	(.020)	(.019)	(.022)	(.014)
Additional Registrations	-.043***	.006	-.011	-.025*	-.026***
	(.011)	(.017)	(.015)	(.014)	(.010)
Change in Disease Status	.009	-.029	.007	.008	.028
	(.036)	(.029)	(.035)	(.035)	(.028)
Change in Licensee Status	.051**	-.002	-.003	.007	.039**
	(.025)	(.018)	(.019)	(.020)	(.017)
Compounds Identified	-.017	.014	-.014	.042	.002
	(.015)	(.022)	(.016)	(.026)	(.014)
Development Continuing	.009	-.002	.035**	.000	.011
	(.015)	(.015)	(.017)	(.016)	(.011)
First Registrations	-.008	.019	.001	-.027***	-.008
	(.009)	(.013)	(.011)	(.007)	(.007)
Global Status Reversion	-.066*	-.009	.078	.105	.035

	(.035)	(.051)	(.079)	(.110)	(.043)
Mechanism Identified	.007	.029	.010	-.001	.029
	(.025)	(.027)	(.025)	(.028)	(.020)
Names Granted	.007	.043	-.001	.017	.023
	(.022)	(.027)	(.023)	(.026)	(.017)
New Chemical Structure	.002	.068***	.001	-.004	.026**
	(.017)	(.020)	(.018)	(.018)	(.013)
New Disease	.014	.000	-.001	.021	.017
	(.018)	(.018)	(.018)	(.020)	(.017)
New Therapeutic Activity	.014	.008	.001	.031	.023*
	(.017)	(.016)	(.016)	(.019)	(.012)
Novel Target Reported	-.049	-.001	.057	.069	.021
	(.064)	(.080)	(.083)	(.088)	(.070)
Registration Submission	-.017**	.009	.029**	.017	.010
	(.008)	(.012)	(.014)	(.014)	(.008)
Suspended Product	.047	.027	.019	.017	.010
	(.032)	(.029)	(.028)	(.030)	(.016)
Withdrawn Product	.001	.034	-.023	.043	.001
	(.041)	(.051)	(.041)	(.060)	(.033)
N	13,300	13,300	13,300	13,300	13,300

95% confidence intervals in brackets

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

For robustness, we also include the same analyses we run in the main results section, but utilizing a linear probability model instead of a logistic probability model. The outcomes are very similar to the main analyses, suggesting that our results are robust to different types of probability models. The results of the linear probability model are included below.

Table 7: Linear Probability Model for Effect of Patent Expiration on Various Initiation Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+1	t-3 to t+1
Panel A: Initiation Events					
New Product	.028	.044**	.001	-.007	.030**
	(.017)	(.018)	(.018)	(.019)	(.012)
New Patent Application	.003	.000	-.006	0.000	.008*
	(.007)	(.007)	(.007)	(.007)	(.005)
First Launches	.003	.000	.010	-.011	.004
	(.009)	(.010)	(.010)	(.010)	(.007)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Linear Probability Model for Effect of Patent Expiration on Various Intermediate Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+1	t-3 to t+1
Panel B: Intermediate Events					
Additional Launches	-.012	.013	.011	-.008	.005
	(.013)	(.013)	(.013)	(.014)	(.009)
Change in Global Status	.016	.001	.003	-.006	.006
	(.014)	(.015)	(.015)	.016)	(.010)
Licensing Opportunity	.013	.020	.017	.004	.017**
	(.012)	(.013)	(.013)	(.014)	(.009)
New Licensees	.022	-.005	.025	.036**	.034***
	(.015)	(.015)	(.015)	(.016)	(.010)
Orphan Drug Status Granted	-.004	-.003	.016*	.000	.002
	(.008)	(.008)	(.008)	(.009)	(.006)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Linear Probability Model for Effect of Patent Expiration on Various Termination Events

	(1)	(2)	(3)	(4)	(5)
	t-3	t-2	t-1	t+1	t-3 to t+1
Panel C: Termination Events					
Product Discontinued	-.005	.015	.006	-.006	.004
	(.012)	(.012)	(.013)	(.013)	(.009)
Licences Discontinued	.019**	-.002	.006	.009	.015**
	(.009)	(.010)	(.010)	(.010)	(.007)
N	13,300	13,300	13,300	13,300	13,300

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$