Competition and Executive Compensation: Evidence from Pharmaceutical Breakthrough Designations

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Abstract

We study the effects of competition shocks on executive compensation. Breakthrough Therapy Designations (BTDs) instrument shocks to the product market position of BTD-recipients' rivals. Rivals respond by increasing option-based compensation for CEOs and other executives. They also subsequently escalate developments of new drugs. Our results corroborate theoretical models wherein (i) firms facing competitive pressures optimally intensify innovation, and (ii) stock options encourage executives to undertake such innovation.

Keywords: Competition; Executive Compensation; Options; Incentives

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1. Introduction

In the face of enhanced competition, firms must adapt their strategies to preserve value. The popular refrain is to innovate. Arrow (1962) develops a theory in which innovation is more value-enhancing for firms under competitive pressure than under monopolistic conditions, suggesting that firms should increase innovation when competition intensifies. In support, Blundell, Griffiths, and Van Reenen (1999) and Bloom, Draca, and Van Reenen (2016) present empirical evidence that competition spurs innovation.

However, risk-averse executives may withhold efforts to boost innovation because "innovation is intrinsically risky and progress more erratic than with standard investments" (Holmstrom, 1989, p. 311). Holmstrom argues that even risk-neutral executives are averse to risky projects and deviate from the standard net present value rules, because they are "carrying (by design) some undiversified risk" (p. 311). Manso (2011) confronts this concern and studies how incentives should be structured when the principal needs to motivate the agent to increase innovation. He shows that the optimal contract tolerates early failures and rewards long-term success. Unlike standard pay-for-performance schemes, executive stock options meet both criteria. Thus, Manso (2011) concludes that the optimal contract that motivates innovation includes stock options, whereas standard pay-for-performance schemes could adversely affect innovation. The conclusion falls in line with an extensive literature that proposes that options encourage managerial risk-taking, including Jensen and Meckling (1976), Haugen and Senbet (1981), Smith and Stulz (1985), and Guay (1999).

Complementing the theory, several empirical studies examine how competition shocks affect executive compensation. One strand of literature, including Hubbard and Palia (1995), Crawford, Ezzell, and Miles (1995), and Cuñat and Guadalupe (2009a), studies banking

deregulation as a competitive shock. The collective evidence suggests that banks respond through increases in total pay as well as pay-performance sensitivity, while showing modest increases in stock options. Another strand of literature examines competition shocks in international settings. Cuñat and Guadalupe (2009b) report that increases in foreign competition—via tariffs or exchange rate shifts—increase pay-performance sensitivity. Bakke et al. (2022) study tariff cuts and find that competition reduces risk-incentive pay from stock option grants. Lie and Yang (2022) find that instrumented import competition from China decreases stock grants but does not affect stock option grants among US manufacturing firms. Overall, there is at best mixed evidence that increases in competition are met with increases in risk-incentive pay by affected firms.

We submit that there are a couple of plausible explanations for the disconnect between past empirical results and the joint prediction of Arrow (1962) and Manso (2011) that competition spurs the use of options to encourage innovation. First, the empirical studies capture more than causal effects. Cuñat and Guadalupe (2009a) study a period of secular shifts in the banking industry as well as the broad economy, either of which are likely culprits to explain compensation policy changes. Relatedly, Lie and Yang (2022) report evidence that changes in tariffs and exchange rates are highly endogenous. The second explanation is that past studies focus on the banking and manufacturing sectors, where innovation is a secondary strategic tool. Thus, they are inadvertently rigged against finding changes in risk-incentive pay meant to spur innovation.

We reexamine how competition affects risk-incentive pay using the pharmaceutical sector, which is ideal for testing the joint theories of Arrow (1962) and Manso (2011). Innovation is a primary strategic tool in the pharma sector because pharma firms continuously aim to develop products that meet unresolved or emerging medical needs, and successful innovations enjoy strong patent protection for numerous years. Furthermore, periodic shocks to competition are common in

the pharma sector, as firms successfully develop and launch products that steal market share from one another. The last decade offers a unique way to identify these shocks.

In 2012, the Food and Drug Administration (FDA) introduced an expedited pathway program, the breakthrough therapy designation (BTD) program. It is designed to facilitate and expedite the approval of therapies that demonstrate substantial improvements over available treatments in a therapeutic area. BTD events represent significant competitive shocks to *rival* firms, defined here as other firms working in the same therapeutic areas as the BTD-recipient firm (Garfinkel and Hammoudeh (2022)). We further argue that the shocks are exogenous to rival compensation structures – see below. Armed with a series of BTD shocks scattered across time and therapeutic areas, we examine their impact on the structure of executive compensation at rival firms. Our test sample also accounts for heterogeneity in rivals' exposure to BTD shocks. That is, we identify sub-groups of *afflicted* rivals, defined as those experiencing progressively worse abnormal returns to the BTD shock events.

We begin by establishing that rivals and control firms (defined later) exhibit similar ex-ante levels and trends in the primary compensation measures, including the value of option grants and the percentage of total compensation that stems from option grants. Thus, any difference in the risk-incentive compensation measures across rivals and control firms *after* a BTD shock is unlikely to be the result of a prolonged trend.

Our main analysis examines the effect of BTD shocks on compensation. Difference-in-differences estimates show a post-shock divergence in the primary compensation measures. Both the level (value) of option grants, and its fraction of total compensation, increase for rival firms relative to control firms in the year after BTD. The effect increases as we sub-sample on increasingly afflicted rivals. It is also larger for CEOs compared to other executives. Conversely,

other compensation variables, including salaries, bonuses, and stock grants, remain similar for rival firms compared to control firms after the BTDs, regardless of the extent to which the rival appears afflicted. We conclude that BTD shocks prompt afflicted rivals to boost risk-inventive pay.

The most obvious reason for firms to boost executives' risk-incentive pay is to encourage innovation. Thus, we extend our analysis to explore whether rival firms—fortified with the new stock options in the executive rank—shift resources toward riskier innovation. Consistent with Manso (2011), we find that afflicted rivals are more likely to initiate new drug projects. Moreover, many of the new projects require new technology or prolonged development, and they are therefore particularly gutsy. While we cannot establish clear causality between the increase in options and the risky development activities, we are inclined to attribute part of these activities to the options and conclude that the options have the desired effect.

Overall, we report that competitive pressures on pharma firms trigger enhanced risk-taking incentives in the form of more stock options granted to upper management, along with riskier drug development projects. Our results dovetail with Arrow's (1962) implication that firms should increase innovation in response to competitive pressure and Manso's (2011) contention that stock options contain the requisite structure to motivate innovative activities. However, our results differ notably from those in other empirical studies of how competition affects compensation structure. We argue that our use of BTDs is a more powerful instrument for establishing a causal effect of competition on compensation than past studies, because BTDs vary in both the time-series and cross section and are exogenous to the existing compensation structure of rival executives. Furthermore, we argue that our pharmaceutical setting, in which innovation is a first-order strategic activity, is particularly suited to test the combined predictions of Arrow (1962) and Manso (2011).

Thus, we contribute to the literature by shedding a skeptical light on prior empirical results and by corroborating past theory.

We also contribute to the literature on the empirical effect of competition on innovation, although this is not our primary focus. Among the recent and influential studies in this literature, Bloom, Draca, and Van Reenen (2016) report that import competition leads to higher R&D expenditures in a sample of European firms, whereas Hombert and Matray (2018) and Autor, Dorn, Hanson, Pisano, and Shu (2020) report that import competition leads to lower R&D expenditures among US manufacturing firms. Our study differs in that we focus on firms in the pharma sector, which rely on innovation as their primary competitive response and for which we have granular information about individual drug projects. We find evidence that their R&D is shifted toward higher-risk areas, including the development of new drugs that use new technologies. We should also note that Garfinkel and Hammoudeh (2022) find that BTDs *on average* discourage rivals from continuing developments in the shocked therapeutic area, complementing our results that resources are shifted to new arenas.

2. The pharmaceutical setting and data description

2.1 Institutional background

The biopharmaceutical industry is well suited for investigating the effect of competition on risk-incentive pay and innovation based on the theoretical frameworks of Arrow (1962) and Manso (2011). First, long-term innovation is crucial to the survival of pharmaceutical firms. Before a firm can market and sell a drug, it must obtain FDA approval. The drug-approval process entails costly and rigorous clinical development to demonstrate both safety and efficacy of a drug. It can take between 5 and 20 years to obtain FDA approval to market a drug (Brown et al., 2021). In addition, drug development is associated with high uncertainty. Of every 100 drug projects in the preclinical

stage (i.e., early in development and focusing on laboratory and animal testing), roughly one project advances and eventually obtains FDA approval (Wouters et al., 2020).[1] As another indicator of high uncertainty and risk, most firms are precommercial without any FDA-approved products, i.e., they only have drug projects under development.[2,3] Finally, after obtaining drug-approval, firms are granted strong patent protection for numerous years. Overall, the pharmaceutical industry rewards long-term successes and has a high incidence of early failures, matching the conditions of Manso (2011).

Second, the market for pharmaceutical drugs is highly competitive. New products are continually developed and successfully launched, causing rival firms to lose market share and perhaps abandon drug development (e.g., Garfinkel and Hammoudeh (2022); Krieger (2021)). Put differently, there is entry/exit across the many therapeutic markets available to pharmaceutical firms. Because of continuous progression and discoveries from development activities, rivals must often confront new threats; they may retreat, transition to a new therapeutic area, or retaliate.

Third, breakthrough therapy designations (BTDs) allow us to identify transformational product introductions (i.e., the greatest competitive shocks) at an early stage.[4] The BTD program was established in 2012, allowing the FDA to designate drugs that are "intended to treat a serious condition and that preliminary clinical evidence indicates may demonstrate substantial

[1] Furthermore, Hay et al., (2014) estimate that only 10.4% of drugs that reach the first stage of *human* trials (i.e., phase-I clinical trials) are eventually approved.
[2] Technically, there is a distinction between the terms "drug" and "drug project." A drug can be developed to target several medical conditions, while each drug-medical condition pairing is a drug project. Notably, the FDA approves a drug for a specific medical condition if the drug's human clinical testing results demonstrate its safety and efficacy in treating that medical condition.
[3] In our final sample, 80% of firms were precommercial status at one point in time.
[4] In fact, BTD drugs are regularly mentioned as sources for significant competition in the financial statements of rival firms. For example, in the 2016 10-K, Bind Therapeutics state "our most significant competition comes from immunotherapies, including nivolumab and pembrolizumab", both of which received a BTD award in 2015. The 2014 10-K of Cocrystal also references Gilead Sciences' two BTD-awarded Hepatitis C treatments, Harvoni and Sovaldi (both of which were designated in 2013), as competitors that significantly changed the competition in the area.

improvement over available therapies" (Sherman et al., 2013). While the BTD program is the fourth addition to the FDA's expedited approval pathway programs, it tops the ranking of how FDA resources are prioritized (Senior, 2013). Drugs with BTDs benefit from the organizational commitment of FDA senior managers, intensive guidance on efficient drug development programs, and higher likelihood of, and quicker, FDA-approval.[5] Upon approval, BTD drugs are perceived as superior (Krishnamurti et al., 2015; Kesselheim et al., 2016), and anecdotal evidence suggests that they are likely to dominate their therapeutic markets.[6]

Finally, the strict regulatory reporting requirements in the pharmaceutical industry provide detailed descriptions of products and projects, including the target therapeutic market, the target actions (i.e., technology) of drugs, and the progress of projects. This granular description allows us to identify (i) the rival firms in a narrowly defined therapeutic area, which is imperative to our identification strategy, (ii) the extent of a rival firm's exposure to a product market shock (e.g., the fraction of all of a rival's products that target the shocked market) and (iii) how rival firms respond *at the project level* to a product market shock.[7] In short, we can examine the real effects of competition shocks (BTDs) on rival firms' compensation structure/strategies and their transfer of resources to riskier projects.

[5] Hwang et al., (2018) find that for a sample of cancer drugs, the median time from Investigational New Drug (IND) application (marking the initiation of human trials) to first FDA approval was 5.2 years for breakthrough-designated drugs, compared to 7.1 years for non-breakthrough-designated drugs. Furthermore, Garfinkel and Hammoudeh (2022) find that BTD drugs are 3 times as likely to receive FDA approval relative to comparable control drugs.

[6] For example, a report published by Vantage in 2018 highlights the growing dominance of Merck's Keytruda in the non-small cell lung cancer therapeutic market. The report states that Keytruda's competitors, "the boat has sailed, and Keytruda has left them fighting over what is at best a vanishingly small slice of the pie."

[7] Johnson & Johnson (JNJ) is one example on how product-level data better identifies firms affected by a market shock, relative to firm-level data, is. According to their 2022 10-K report, JNJ operates in 3 segments: pharmaceutical preparations (which accounted for about 54% of annual revenues), consumer health (16%) and medtech (30%). The Compustat annual files (CRSP) indicates that JNJ's primary SIC code is 2834 (3841), which identifies the pharmaceutical preparations (surgical and medical instruments) industry. This highlights the problems with using firm-level industry classifications to identify affected firms that operate in multiple segments.

2.2 Drug development, therapeutic markets, target actions, and BTD data

2.2.1 Drug development data

Our drug development data come from Clarivate Cortellis Competitive Intelligence and include pharmaceutical innovation data obtained from company records, conferences, and other public sources. The data has been used in recent studies (e.g., Krieger (2021); Krieger, Li, and Papanikolaou (2021); Hermosilla (2021)). As of the end of 2019, the full sample includes comprehensive development histories and ownership data on over 30,000 drug projects developed by over 5,000 firms targeting about 500 medical conditions.

Our sample construction begins in 2010 with approximately three years of data before the first awarded BTD in December 2012. The sample ends in 2019 due to availability of our drug development data. We only keep drug-indications developed for U.S. markets. We drop drug projects with missing key development dates and "zombie" projects.[8] One challenge with identifying the correct owner of a drug at a certain point in time is that drugs are often acquired or out-licensed. Furthermore, a drug may be developed by a subsidiary of another firm. Therefore, we follow the process from Garfinkel and Hammoudeh (2022) to match each drug project to its correct owner in each year of the sample period.[9] The resulting sample includes 29,672 drug projects developed by 4,392 firms.

[8] Firms are often reluctant to report project suspensions. Consistent with Li, Liu, and Taylor (2023), we assume that "zombie" projects are discontinuedthree years after a "no development reported" designation in the Cortellis data.
[9] Garfinkel and Hammoudeh (2022) conduct an extensive search to identify the correct owner of drugs in the Cortellis data. They use exact and fuzzy matching methods to match firms in Cortellis to firms in the SDC platinum database using firm names. They identify subsidiaries using the detailed drug development history descriptions in Cortellis.

2.2.2 Therapeutic markets and target actions (technology)

A therapeutic area is the medical condition that a drug is meant to treat. A single drug may be developed for several indications.[10] Cortellis reports all indications a drug is intended to treat, e.g., "Metastatic Breast Cancer." In some cases, two or more indications refer to the same condition, e.g., the indication "liver disease" is likely the same indication as "liver cirrhosis" (Krieger, 2021).[11] To identify potentially competing products within a therapeutic area, we map Cortellis indications to the 9th revision of the International Statistical Classification of Diseases and Related Health Problems classifications (herein ICD-9).[12] We define a *market* by grouping drugs with the same ICD-9 code. This process results in 475 unique ICD-9 therapeutic markets.

Furthermore, we define the *technology* of a drug based on its molecular target action. The target is the molecule in the body that the drug changes, and the action refers to the type of change. For example, mRNA vaccines work by inducing the muscle cells near the injection cite to produce spike proteins similar to those found on the surface of the SARS-CoV-2 virus. This causes the immune system to produce specific antibodies that bind to the spike proteins of the virus and neutralize it. A single drug compound may also have multiple target actions. We identify 44,488 unique target actions in our sample.

2.2.3 Breakthrough therapy designations

We follow Garfinkel and Hammoudeh (2022) to identify BTD events and grant dates. Specifically, we collect information on breakthrough designations from the Friends of Cancer Research (FOCR) website.[13] FOCR identifies each BTD drug name, the announcement date, the

[10] We use the terms "medical condition," "indication," "ICD-9 code," and "therapeutic market" interchangeably when referring to the medical condition that is targeted by a drug project.
[11] Approximately 35% of drugs in our data are developed for more than one indication.
[12] We thank Manuel Hermosilla for sharing the mapping data between Cortellis indications and ICD-9 codes.
[13] https://www.focr.org/breakthrough-therapies

sponsoring firm, and the indications for which the BTD was granted. We manually match the FOCR data to our drug development data using drug names. If a BTD is granted to more than one drug or more than one firm, we treat each as a separate BTD event.[14] We validate announcement dates via firm financial statements, FDA disclosures, and business media articles. We also crosscheck our dates with the 143 BTDs in the online supplementary appendix of Hoffmann et al. (2019). Finally, we drop five BTDs that were rescinded. Our final sample of BTD awards include 253 unique BTDs awarded to 107 firms in 93 ICD-9 markets from December 2012 through December 2019.

2.3 Executive compensation details

Executive compensation details are obtained from a variety of sources. We first collect data from ExecuComp and Institutional Shareholder Services (ISS) for large firms in our sample. For all remaining firms in Cortellis not covered by each of these datasets (mostly smaller, precommercial firms), we manually collect data from the Summary Compensation Table in firms' annual proxy statements (and if necessary, from annual reports). We collect compensation details for the CEO and the other named executive officers (NEOs) that are the most highly compensated (five or three) individual officers of the firm. We record the form of compensation (salary, bonus, stock, options, etc.) and the disclosed titles of each listed executive as of the end of the fiscal year to identify CEOs, CFOs, and other NEOs. We define an indicator, *CEO* (*CFO*), equal to one if the executive was listed as the CEO (CFO) at the end of the firm-year and zero otherwise.

The objective of this paper is to study the effect of competition shocks on the risk-incentive pay of management. Therefore, we restrict our focus to annual compensation via stock options, stock grants, salary, and total compensation. We calculate the natural log of each compensation

[14] We crosscheck our BTD labels on drugs using the "Regulatory Designation" field in Cortellis, which indicates whether a BTD was granted but does not identify the grant date or the designated drug-indication(s).

variable winsorized at the 1st and 99th percentiles. We also calculate the fractions of total (winsorized) compensation that are comprised of each component (stock options, stock, and salary).

2.4 Rival risk-taking measures

To empirically examine the predictions of Arrow (1962) and how rival firms respond to BTD events, we create three risk-taking measures. As noted above, the pharmaceutical industry offers detailed reporting of drug products and projects. This allows us to construct granular measures of drug-project innovations including new initiations, introduction of a new technology not previously used, and development of a drug with lengthy gestation time for a particular therapeutic market. Given these innovation project-level indicators, we can aggregate up to the firm level.

We begin with the most basic version of drug innovation (to the firm) and identify the years in which a firm begins development of a new project. *Drug Initiation* is an indicator variable that equals one if the firm initiates (begins developing for the first time) a new project in the given year. Second, we identify whether a new drug project utilizes a new technology (i.e., target action) that was not previously used by the firm before now, on any of their existing drug projects. The firm's lack of experience with the new technology increases the uncertainty associated with the development's success. *New Technology* is an indicator variable equal to one if the firm starts developing a new drug project with a new technology in the year.

Our final risk-taking measure is based on the length of time a drug project is expected to be under development. Drug development is inherently risky due to its high cost, lengthy development times, and low success rates (again, see Hay et al. (2014)). When the time under development is longer than average, perhaps due to the complexity of treatments in that therapeutic area, the risk is heightened. Why might firms choose to develop projects in markets with lengthy

development times? We suggest that firms may develop projects in these markets in the hopes of obtaining economic rents upon success. Indeed, we find that such markets have significantly fewer competing drug projects, and more importantly, fewer approved-for-sale products.[15]

We calculate a therapeutic market's average development time as the number of years to complete each clinical trial (i.e., Phase-I, Phase-II, *or* Phase-III) for each drug project in that market, and then compute a grand average across all such projects within the therapeutic market. *Lengthy Development Time* is an indicator variable set equal to one if the firm begins developing a new drug project in a market with an average development time above the median such value in the Cortellis sample.

It is worth noting that each of these variables are comprised of drug-level data only available due to the detailed reporting requirements of the industry. While we aggregate drugs and project-level variables to the firm-level, each measure is more granular than typical firm-level proxies for firm risk-taking (e.g., R&D expense in Compustat) and should theoretically better reflect changes made by rivals following BTD events. For example, if a firm responds to a competitor receiving a BTD by reallocating scarce resources from an existing project that was targeting the BTD-shocked market, to a new project using a new technology (target action) with an above median development time, all three of our risk-taking measures would reflect this reallocation. Conversely, an aggregated measure, like R&D expenses, may not capture this reallocation *at all*.[16]

[15] In untabulated results, we use a sample with observations at the therapeutic market-level and run two regressions with number of drug projects (number of approved products) as the dependent variable in the first (second) regression. In both regressions, the main independent variable is the average development time (in quarters) of a market. We find a negative and statistically significant relationship between both dependent variables and development time.

[16] Unlike our drug-based measures for risk-taking, across the main sample of all rivals we find no significant effect of BTD shocks on R&D expenses.

2.5 Construction of the firm-level and executive-level samples

We study the overlap of firms covered by Cortellis that also have executive compensation details during 2010–2019. To avoid potential confounding effects of BTD awards on *recipient* firms' compensation decisions, we exclude all annual observations of such BTD-receiving firms following their receipt of a BTD. Our data requirements yield an initial sample of 3,118 firm-year observations across 544 unique firms with both drug development and executive pay details. Among these firms, we identify 4,549 executives (955 unique CEOs) and base our main analysis on this sample at the executive-firm-year level.[17]

2.6 Identifying afflicted rivals

To assess the effect of the BTD on competitors, we first identify all rival firms. Rivals are defined as firms that were developing a drug project (or selling an approved product) in the same therapeutic area that experienced the BTD. Importantly, rival firms are not receiving the BTD; rival firms are considered shocked as their competitive position is likely weakened.

Broadly, we study compensation and risk-taking behavior of rivals in the five years surrounding the BTD event (*T–2*, *T–1*, *T*, *T+1*, and *T+2*, where T is the BTD award year). We consider each rival to be shocked in the three years including and after the BTD award year (*T*, *T+1*, and *T+2*). Naturally, not all rivals are equally affected by BTD events. For example, rivals that are highly exposed to a shocked market—those with a significant portion of their drug portfolio in that market—are likely more afflicted by the shock than larger rivals that compete in a diversified set of several markets. Since the objective of our study is to examine the responses

[17] This main sample has nearly twice as many unique CEOs as unique firms because of turnover in CEOs.

of rivals that are most sensitive to the shock (those whose competitive position is weakened most), we focus our attention on what we define to be afflicted rivals.[18]

We identify afflicted rivals via event study reactions to the BTD events. Specifically, we examine all rivals' three-day cumulative abnormal stock returns (labeled CARs) centered around each BTD announcement date.[19] For our 253 BTD events, we have about 5,300 rival reactions to potentially explore. However, each compensation variable we seek to explain is annual. Therefore, our selection of afflicted rivals must also consider the annual cadence of compensation decisions at firms.

We recognize that firms often set executive pay of year *T+1* near the fiscal year end of year *T* (e.g., firms with fiscal year ends in December may set executive pay for 2016 in December of 2015). Furthermore, we note that 95% of firms in our sample have a December fiscal year end. Given these two observations, we assume that firms need two months to incorporate the information relayed by a year *T* BTD shock, into their executive compensation decisions for year *T+1*, and therefore shocks occurring in November or December of year *T* are only reflected in a firm's year *T+2* pay.[20] Now we can assign BTD shocks to the appropriate year of executive compensation observation.

Next, we account for multi-shock years. In the event that a rival firm experiences two BTD shocks during the year, we retain the event that resulted in the lowest (most negative) CAR value. In other words, we allow each rival to have exactly one BTD shock each year they are shocked.

[18] It is possible that even large, diversified firms may recognize BTD events as significant game changers and alter their executive compensation practices. However, we expect this to bias against our results and make it more difficult to discern a statistical difference between the afflicted rivals and the control firms.

[19] We use a market model with parameters estimated over [−271, −21], relative to the BTD announcement date, and calculate CARs over the three-trading day window [−1, +1], where 0 is the announcement date.

[20] Correspondingly, BTD announcements that occur in January through October of year *T* are considered to be shocks to rivals in the same year *T*. Nevertheless, we find similar results if we do not make this two-month lag modification, or if we consider shocks occurring in October through December of year *T* as shocks to the firm in year *T+1*.

We then sort the CAR values of these unique rival-year observations into four, three, or two quantiles regardless of the shock year.[21,22] We label rivals as *afflicted* rivals in year *T* if their lowest CAR during year *T* was in the lowest quantile of all rival CARs across all years. Finally, for each afflicted rival, we define five event-year indicators, *Rival Shock (T–2, T–1, T, T+1,* and *T+2),* for each of the five years centered around the afflicted rival BTD event year.[23]

The final sample includes two types of firms. Afflicted rivals, defined as rival firms within the lowest quantile of CARs, and control firms. Control firms, therefore, include firms that did not experience a BTD event in the five-year window, or rivals that were not defined to be afflicted.

2.7 Sample Descriptive Statistics

Table 1 presents variables in the executive-level pay data. Panel A shows the average values of the BTD rival indicators. About 6.5% (9%, 13.5%) of observations correspond to a year in which a rival experienced an afflicting shock when using quartile (tercile, median) sorts. The narrower the definition for afflicted rivals, the more afflicted they are. Our prior is that the more stringent the definition used to define afflicted rivals, the more pronounced the firms' responses.

In Panel B of Table 1, both the executive compensation level (in natural logs) and component percentage variables are summarized. The summary statistics indicate that CEOs receive higher compensation packages relative to non-CEO executives, with average CEO total compensation of about $2,100,000 and average non-CEO total compensation of about $1,300,000. Irrespective of using the level or percentage variables, stock options constitute the largest component of

[21] We sort CARs into quantiles regardless of the shock year because we wish to identify the most afflicted rivals over the entire sample period. This is particularly important because the distribution of afflicted rivals is not even across years, e.g., more rivals experienced afflicting events in 2015 than in 2013.

[22] The average values of CAR for events in the lowest quartile, lowest tercile, and below median groupings are respectively –10.8%, –9.7%, and –8%.

[23] If a rival experiences multiple afflicting BTD events in consecutive years, then more than one rival-year indicator may equal one. For example, if a rival experiences two afflicting BTD events in 2014 and 2015, then for that rival's year 2013 observations a value of one is assigned to both indicators *Rival Shock (T–1)* (referencing the 2014 event) and *Rival Shock (T–2)* (referencing the 2015 event).

compensation for executives in our sample. This finding is consistent with those reported in business media outlets.[24] Furthermore, the finding that about 38% (an average of about $760,000 in stock options) of CEO pay is in the form of stock options is consistent with previous findings.[25] They also receive an average of 13% of their total compensation in the form of stock grants (worth about $260,000 on average), and 30% in the form of salary compensation (worth about $600,000 on average). Panel B suggests that relative to non-CEO executives, the compensation packages of CEOs have higher proportions of performance-based compensation and lower proportions of cash compensation. This result motivates our focus on subsamples partitioned by executive type, and we expect to see a stronger response to CEOs' compensation structures following a BTD shock.

3. Empirical Design and Results

3.1 Executive compensation around BTD events

We examine the effect of BTD shocks on the structure of executive compensation at rival firms using difference-in-differences (DiD) regressions. This analysis compares afflicted rivals to control firms before and after the BTD events. We run the following general model via OLS:

$$Compensation_{e,f,t} = \sum_{n=-2}^{n=2} \beta_n Rival\ Shock\ (T+n)_{f,t,s} + X_{f,t} + \emptyset_f + \gamma_t + \delta_s + \varepsilon_{e,f,t} \quad (1)$$

where *e* indexes executive, *f* indexes firm, *t* indexes calendar year, and *s* indexes BTD shock vintage year (described below). The dependent variable, *Compensation,* is either a compensation level variable or a compensation percentage (of total) variable. The level is always calculated as the natural log of the compensation component for executive *e* in year *t*. The component percentage

[24] For example, an article published by the biopharmaceutical research institute, WTW, states that the percentage of stock options in the biopharma sector is more than double that of the next sector. Source: https://www.wtwco.com/en-US/Insights/2021/01/biopharma-industry-still-relies-on-stock-options.

[25] For example, in the article referenced in the footnote above, stock options constitute 46% of CEO pay. We note that our finding of 38% includes both established "big pharma" and precommercial biotech, whereas their sample focuses solely on smaller biotech.

variable is calculated as the percentage of executive *e*'s total compensation that is in a given component in year *t*. *Rival Shock* is the main independent variable of interest. We examine compensation variation centered around the BTD event, by including the *Rival Shock* indicator variables *(T–2, T–1, T, T+1, and T+2)*, where T is the BTD event year for the afflicted rival.

$X_{f,t}$ represent firm-level controls. *Precommercial* is an indicator variable equal to one for firms with no approved projects, and proxies for overall firm maturity and competitive position. *Firm total projects* measures the number of current projects the firm has approved or is currently working on, and proxies for firm size. $\emptyset_f$ are firm fixed effects, γ_t are year fixed effects, and δ_s are BTD shock vintage year fixed effects.[26] We cluster standard errors at the firm level.

Before drawing any causal inferences, DiD estimations require that the parallel trends assumption be satisfied. That is, the average outcome in treated and comparison populations would have followed "parallel trends" in the absence of treatment. In our context, executive pay should not appear significantly different between afflicted firms and control firms *before* the BTD shock. Thus, we do not expect to see any noticeable differences between afflicted and control firms, if any, until after the shock occurs. The regression model in equation (1) is effectively a test of this parallel trends assumption. The *Rival Shock* indicators capture the differential effect of BTD shocks on executive pay in the years before and after the shock year. We investigate the validity of the parallel trends assumption by running OLS regressions using equation (1) and examining the coefficients on the *Rival Shock* indicators in the two years before the shock. Table 2 and Table 3 report the results when using compensation levels and compensation component percentages, respectively.

[26] The vintage year FEs are indicators for the year in which an active rival is being shocked. For example, if rival X was shocked in 2016, then for all five of this rival's observation-years from 2014 to 2018, it will have a value of one for the "shock year 2016 indicator". There are only seven of these indicators, since the first shock occurred in 2013 and last in 2017.

Table 2 reports regression results separately for a sample of only CEOs and for a sample using all named executive officers. Panels A, B, C, and D, respectively, use the (natural log) of stock options, stock grants, salary, and total compensation as the dependent variable. In all panels, the results support the parallel trends assumption, i.e., the coefficients of the indicators in the two years before the shock are not statistically different from zero. Statistically significant differences in executive pay levels between afflicted rivals and control firms begin to appear only *after* the BTD events.

Turning to rival responses to BTD shocks, Panel A of Table 2 (where the dependent variable is the natural log of stock options) suggests that afflicted rivals respond by significantly increasing the risk-incentive pay of executives in the first year immediately after the shock. Furthermore, as we define afflicted rivals more stringently, we observe larger coefficients and observed adjustments in risk-incentive pay.

The adjustment in risk-incentive pay is evident in both the CEO sample and the full executive sample. However, the coefficient magnitudes suggest that this effect is more economically pronounced for CEOs. Moreover, across both CEOs and other execs, we find scant evidence that afflicted rivals alter their executive stock, salary, or total compensation levels following BTD events relative to the set of control firms.[27]

Table 3 reports the results from OLS regressions when replacing the dependent level variable with compensation *component percentages*. The results are strikingly similar to those reported in Table 2. That is, in the first year after a BTD shock, afflicted rivals increase the percentage of executive stock option pay relative to control firms. Furthermore, the coefficients on *Rival Shock (T+1)* again increase as we tighten the definition of afflicted rivals (i.e., quartile sorts relative to

[27] In Panels B, C, and D of Table 2.

median sorts). We observe a slight reduction in the percentage of pay tied to stocks and salary in the first year after the shock, although the statistical significance is weak in several specifications.

Overall, the evidence suggests that afflicted rivals view higher levels of risk-taking as an appropriate response to competitive shocks and adjust executive compensation accordingly. In the next section we investigate the risk-taking activities of rivals following BTD shocks.

3.2 Rival risk-taking around BTD events

Given our evidence of rival-firm adjustments to risk-incentive pay following BTD shocks, we now explore whether afflicted rivals follow up the shock with more observed risk-taking. We specifically estimate the effect of BTD shocks on rivals' risk taking using difference-in-differences (DiD) OLS regressions, via the following model:

$$Risk_{f,t} = \sum_{n=-2}^{n=2} \beta_n Rival\ Year\ (T+n)_{f,t,s} + \emptyset_f + \gamma_t + \delta_s + \varepsilon_{f,t} \quad (2)$$

where *f* indexes firm, *t* indexes calendar year, and *s* indexes BTD shock vintage year. The sample consists of all rival firm-years with available compensation data and drug development data. The dependent variable, *Risk*, is one of the three indicators that proxy for risk-taking (described in Section 2.4). *Rival Shock* is the main independent variable of interest. We again have five *Rival Shock* indicators, one for each of the five years centered around the year of the BTD shock. The five indicator values equal one for shocks that associate with the rival being afflicted, zero otherwise (i.e., control observations). $\emptyset_f$ are firm fixed effects, γ_t are year fixed effects, and δ_s are BTD shock vintage year fixed effects. Standard errors are clustered at the firm level.

Once again, the regression model in equation (2) effectively serves as a test for the parallel trend assumption. If this assumption holds, we expect the coefficients on the rival shock year indicators to be insignificant in the two years *before* the shock year; any difference should only appear after the shock.

Table 4 presents summary statistics on the shock year indicators and the risk-taking measures. The data in Panel A suggest that the distribution of shock year indicators in the firm-level sample is comparable to that of the executive-level sample described in Panel A of Table 1.

Panel B of Table 4 displays descriptive statistics for the risk-taking variables. Drug initiations are very common with at least one drug initiation in about half of the firm-year observations (54.9%). Initiations of drugs using a new technology that was not previously used by the firm appear less common (29.6%). Finally, drug initiations in markets with lengthy development times appear somewhat common (38.2%).

Table 5 reports the results from OLS regressions of firm risk-taking on shock year indicators. Panel A reports these results using the *Drug Initiation* indicator as the dependent variable. The results suggest that afflicted rivals are significantly more likely to initiate a new drug project in the first year after the shock. Furthermore, rivals that were more afflicted by the shock (defined on quartile sorts) are more likely to initiate a drug project relative to less afflicted rivals (defined on median sorts).

Panel B of Table 5 reports the results from OLS regressions using *New Technology* initiations as the dependent variable. We again observe that afflicted rivals, especially those highly afflicted by the shock, are significantly more likely to initiate drug projects that use new technology, in the first year after being shocked. There is no statistical difference between less afflicted rivals and control firms (in the first model).

Panel C of Table 5 reports results when using the *Lengthy Development Time* indicator as the dependent variable. We observe a higher propensity for more afflicted rivals to initiate projects in markets with lengthy development times. In summary, the results in this section provide

evidence in favor of increased risk-taking by afflicted rivals, and the effect is proportional to the extent of affliction.

If the increase in risk-incentive pay causes afflicted rivals to pivot toward riskier projects, one might expect the increase in project risk to occur in the year *after* the increase in risk-incentive pay, and not in the same year (as we observe here). Nonetheless, it is possible that the decisions on compensation structure precede the investment decisions within the same year, or at least that executives anticipate pending changes in compensation structure when they make the investment decisions. On that basis, our results are consistent with our conjecture that observed increases in option compensation cause the riskier investments. Yet, we cannot entirely rule out an alternative sequence that the BTD shocks first trigger riskier investments, which in turn cause the board to augment the use of options to adapt to the riskier course. We still view this to be in the general spirit of our conjecture.

4. Robustness

We undertake two sets of robustness tests with alternative definitions of afflicted rivals. First, we restrict our analyses to cases in which rivals experience their first BTD shock. In our main tests above, a rival could experience multiple BTD shocks that would cause abnormal returns sufficiently negative to label the rival afflicted, over the course of the sample period. For example, about 60% of afflicted rivals are shocked exactly once using quartile sorts, and of the remainder with multiple shocks, 85% of the shocks occur within two consecutive years. This raises several potential concerns: (i) the first shock might trigger a stronger response than subsequent shocks, perhaps due to anticipation bias; (ii) shock year indicators defined for rivals shocked (sufficiently to be labeled afflicted) at least twice in consecutive years introduce an econometric issue, because several of the shock year indicators for these rivals have a value of one; and (iii) rivals shocked

multiple times likely have a broader portfolio of projects than those shocked only once, and are thus overweighted in the analysis. Restricting our definition of afflicted rival observations to the first shock experienced by the rival that meets the affliction criteria ameliorates these concerns.

Second, we redefine afflicted rivals based on a combination of the CARs (used earlier) and the fraction of the rival's projects that are in the shocked product market (which we label shock exposure). The idea behind combining both elements is that unrelated news potentially distorts the CAR or that the BTD announcements are partially predicted; in either case, the CAR might capture more than just the reaction to the BTD event. Using this alternate definition, a rival is only considered afflicted if it exhibits both a CAR and a fraction of exposed projects in the respective lower and higher halves (or lowest and highest terciles/quartiles) of the distributions.

We rerun the regression models in Tables 2, 3 and 5 using the alternative definitions for afflicted rivals. Tables 6–9 summarize the results.[28] In short, the results are similar to those in the main tests, or perhaps even a bit stronger when using the definition based on the combination of CARs and fractions of exposed projects.[29] Thus, there is no evidence to indicate that our results are attributable to fortuitous categorizations of afflicted rivals.

5. Conclusion

We study how firms adjust executive compensation structure in response to competitive shocks. Based on the theories of Arrow (1962) and Manso (2011), the optimal firm response to heightened competition is to increase innovation, which can be accomplished through greater risk-

[28] The internet appendix includes the complete set of summary statistics for each alternative approach to constructing the sample of afflicted rivals, as well as the accompanying regression results.
[29] In untabulated tests, we define afflicted rivals using *only* the fraction of a firm's drug portfolio in the shocked market and find similar results.

incentive pay. But empirical work in the compensation literature fails to support this prediction. We offer a new approach and new results.

Our analysis focuses on the pharmaceutical industry. This focus carries several advantages, including (i) highly innovation-oriented investments, (ii) detailed investment activity data, and (iii) a set of time-varying cross-sectional shocks to firms' competitive positions in the form of Breakthrough Therapy Designations (BTDs). The BTDs signal the FDA's favorable view of the potential for a drug under development, and expedite the FDA approval process. As a result, rival firms, i.e., those that have competing drug projects with the one that received the BTD, suddenly find themselves at a competitive disadvantage and need to adjust and reposition.

We show that BTD-shocked rivals swiftly and significantly increase their risk-incentive pay after the shocks. In addition, they pivot their drug development projects in new and riskier directions. These actions are consistent with the aforementioned theories for how firms should optimally respond in the face of increased competition.

References

Arrow, Kenneth J., 1962, Economic welfare and the allocation of resources for invention, in Richard Nelson ed.: The Rate and Direction of Inventive Activity: Economic and Social Factors (Princeton University Press).

Autor, David, David Dorn, Gordon H. Hanson, Gary Pisano, and Pian Shu. 2020, Foreign competition and domestic innovation: Evidence from US patents, *American Economic Review: Insights* 2, 357–74.

Bakke, Tor-Erik, Felix Z. Feng, Hamed Mahmudi, and Caroline H. Zhu, 2022, Foreign competition and CEO risk-incentive compensation, *Journal of Corporate Finance* 76, 102241.

Bloom, Nicholas, Mirko Draca, and John Van Reenen, 2016, Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity, *Review of Economic Studies* 83, 87–117.

Blundell, Richard, Rachel Griffiths, and John Van Reenen, 1999, Market share, market value and innovation in a panel of British manufacturing firms, *Review of Economic Studies* 66, 529–554.

Brown, Dean G., Heike J. Wobst, Abhijeet Kapoor, Leslie A. Kenna, and Noel Southall, 2021. Clinical development times for innovative drugs, *Nature Reviews Drug Discovery* 21, 793–794.

Crawford, Anthony J., John R. Ezzell, and James A. Miles, 1995, Bank CEO pay-performance relations and the effects of deregulation, *Journal of Business* 68, 231–256.

Cuñat, Vicente, and Maria Guadalupe, 2009a, Executive compensation and competition in the banking and financial sectors, *Journal of Banking & Finance* 33, 495–504.

Cuñat, Vicente, and Maria Guadalupe, 2009b, Globalization and the provision of incentives inside the firm: The effect of foreign competition, *Journal of Labor Economics* 27, 179–212.

Garfinkel, Jon A., and Mosab Hammoudeh, 2022, Competition and innovation revisited: A project-level view, working paper.

Guay, Wayne R., 1999, The sensitivity of CEO wealth to equity risk: An analysis of the magnitude and determinants, *Journal of Financial Economics* 53, 43–71.

Haugen, Robert A., and Lemma W. Senbet, 1981, Resolving the agency problems of external capital through options, *Journal of Finance* 36, 629–648.

Hay, Michael, David W. Thomas, John L. Craighead, Celia Economides, and Jesse Rosenthal, 2014, Clinical Development Success Rates for Investigational Drugs, *Nature Biotechnology* 32, 40–51.

Hermosilla, Manuel, 2021, Rushed innovation: Evidence from drug licensing, *Management Science* 67(1), 257–278.

Hoffmann, David, Shane Van Dalsem, and Frank S. David, 2019, Stock price effects of breakthrough therapy designation, *Nature Reviews Drug Discovery* 18, 165–166.

Holmstrom, Bengt, 1989, Agency costs and innovation, *Journal of Economic Behavior and Organization* 12, 305–1327.

Hombert, Johan, and Adrien Matray, 2018, Can innovation help US manufacturing firms escape import competition from China?, *Journal of Finance* 73, 2003–2039.

Hubbard, R. Glenn, and Darius Palia, 1995, Executive pay and performance: Evidence from the U.S. banking industry, *Journal of Financial Economics* 39, 105–130.

Hwang, Thomas J., Jessica M. Franklin, Christopher T. Chen, Julie C. Lauffenburger, Bishal Gyawali, Aaron S. Kesselheim, and Jonathan J. Darrow, 2018, Efficacy, safety, and regulatory approval of Food and Drug Administration-designated breakthrough and nonbreakthrough cancer medicines, *Journal of Clinical Oncology* 36, 1805–1812.

Jensen, Michael C, and William H. Meckling, 1976, Theory of the firm: Managerial behavior, agency costs and ownership structure, *Journal of Financial Economics* 3, 305–360.

Kesselheim, Aaron S., Steven Woloshin, Wesley Eddings, Jessica M. Franklin, Kathryn M. Ross, and Lisa M. Schwartz, 2016, Physicians' knowledge about FDA approval standards and perceptions of the "breakthrough therapy" designation, *Journal of the American Medical Association* 315, 1516–1518.

Krieger, Joshua L., 2021, Trials and terminations: Learning from competitors' R&D failures, *Management Science* 67, 5525–5548.

Krieger, Joshua L., Danielle Li, and Dimitris Papanikolaou, 2021, Missing novelty in drug development, *Review of Financial Studies* 35, 636–679.

Krishnamurti, Tamar, Steven Woloshin, Lisa M. Schwartz, and Baruch Fischhoff, 2015, A randomized trial testing US Food and Drug Administration "breakthrough" language, *JAMA Internal Medicine* 175, 1856–1858.

Li, Xuelin, Tong Liu, and Lucian A. Taylor, Common Ownership and Innovation Efficiency, 2023, *Journal of Financial Economics* 147, 475–497.

Lie, Erik, and Keyang D. Yang, 2022, Import penetration and executive compensation, *Review of Financial Studies* 36(1), 281–3316.

Manso, Gustavo, 2011, Motivating innovation, *Journal of Finance* 66, 1823–1860.

Senior, Melanie, 2013, Drugs with breakthrough status charm investors, *Nature Biotechnology* 31, 945–946.

Sherman, Rachel E., Jun Li, Stephanie Shapley, Melissa Robb, and Janet Woodcock, 2013, Expediting drug development—the FDA's new "breakthrough therapy" designation, *New England Journal of Medicine* 369, 1877–1880.

Smith, Clifford W., and Rene M. Stulz, 1985, The determinants of firms' hedging policies, *Journal of Financial and Quantitative Analysis* 20, 391–405.

Wouters, Olivier J., Martin McKee, and Jeroen Luyten, 2020. Estimated research and development investment needed to bring a new medicine to market, 2009–2018. *JAMA* 323, 844–853.

Table 1: Summary Statistics

This table reports the average values of the BTD rival indicators (Panel A) and the executive compensation variables (Panel B). The analysis sample consists of compensation records for 4,549 executives at 544 publicly listed firms from 2010 through 2019. These records correspond to 12,304 unique executive-firm-year observations. The sample excludes the observations of firms that receive a BTD award (i.e., BTD-awarded firms) from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. Afflicted rivals are firms that had significantly negative stock returns (more details below) around the announcement of a BTD award to a competitor in a therapeutic market where the rival was active. Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year.

Panel A reports the average values of the afflicted rival-shock indicators. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *(T±N)* relative to the year the rival experienced the afflicting BTD event. If a rival experiences multiple afflicting BTD events in consecutive years, then more than one rival-year indicator may equal one. For example, if a rival experiences two afflicting BTD events in 2014 and 2015, then for that rival's year 2013 observations a value of one is assigned to both indicators *Rival Shock (T–1)* (referencing the 2014 event) and *Rival Shock (T–2)* (referencing the 2015 event).

Panel B reports the average values of the executive compensation variables. Statistics are reported for the sample of CEOs in columns (1) and (2), and for the sample of all executives in columns (3) and (4). Columns titled "Level" summarize the natural log of the compensation component, whereas columns titled "Fraction" summarize the fraction of a component in the total compensation. All compensation variables are first winsorized at the 1st and 99th percentiles before calculating the natural log or the fractions.

Panel A: Afflicted Rival-Shock Indicators

	Median	Tercile	Quartile
	(1)	(2)	(3)
Rival Shock (T–2)	0.123	0.080	0.059
Rival Shock (T–1)	0.136	0.089	0.066
Rival Shock (T)	0.135	0.089	0.065
Rival Shock (T+1)	0.129	0.084	0.061
Rival Shock (T+2)	0.095	0.063	0.046

Panel B: Executive Compensation Variables

	CEO		All Executives	
	Level	Fraction	Level	Fraction
	(1)	(2)	(3)	(4)
Options	13.508	0.384	12.776	0.344
Stocks	5.241	0.129	5.293	0.125
Salary	13.028	0.302	12.738	0.343
Total Compensation	14.544		14.073	

Table 2: Executive Compensation Levels around BTD Events

The tests in this table examine the effect of afflicting BTD events on rival executive compensation levels, relative to those of control firms. The table presents coefficients from OLS regressions that include firm-, calendar year-, and BTD event vintage year fixed effects, and cluster standard errors by firm. The dependent variables are indicated in the title of each panel and are computed for each executive-year as the natural log of each compensation component. The analysis sample, summarized in Table 1, consists of compensation records for 4,549 executives at 544 publicly listed firms from 2010 through 2019. These records correspond to 12,304 unique executive-firm-year observations. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the afflicting BTD event. Results in the first (last) three columns are reported from tests that use the sample of CEOs (all executives). t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Natural Log of Stock Options					
Rival Shock (T–2)	–0.247	–0.432	–0.505	–0.192	–0.292	–0.443
	(–0.712)	(–1.107)	(–1.153)	(–0.771)	(–0.993)	(–1.303)
Rival Shock (T–1)	0.423	0.349	0.185	0.292	0.133	0.056
	(1.231)	(0.954)	(0.453)	(1.167)	(0.496)	(0.178)
Rival Shock (T)	–0.014	0.080	0.201	–0.170	–0.107	0.038
	(–0.040)	(0.196)	(0.456)	(–0.631)	(–0.343)	(0.107)
Rival Shock (T+1)	0.984**	1.203***	1.318***	0.899***	1.207***	1.221***
	(2.306)	(2.655)	(2.702)	(2.795)	(3.621)	(3.307)
Rival Shock (T+2)	0.985*	0.618	0.791	0.759*	0.607	0.853*
	(1.779)	(1.025)	(1.268)	(1.753)	(1.276)	(1.828)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.405	0.405	0.405	0.349	0.349	0.349
	Panel B: Natural Log of Stocks					
Rival Shock (T–2)	0.037	0.033	–0.199	0.117	0.112	0.188
	(0.101)	(0.078)	(–0.417)	(0.397)	(0.330)	(0.486)
Rival Shock (T–1)	–0.329	–0.173	0.249	–0.555**	–0.248	0.154
	(–0.940)	(–0.420)	(0.549)	(–1.961)	(–0.750)	(0.413)
Rival Shock (T)	–0.701*	–0.538	–0.469	–0.689**	–0.470	–0.227
	(–1.938)	(–1.273)	(–1.029)	(–2.373)	(–1.401)	(–0.604)
Rival Shock (T+1)	–0.175	–0.118	0.046	–0.203	–0.020	0.165
	(–0.382)	(–0.231)	(0.085)	(–0.561)	(–0.050)	(0.382)
Rival Shock (T+2)	–0.007	0.914	0.891	0.145	0.563	0.610
	(–0.012)	(1.395)	(1.223)	(0.297)	(1.089)	(1.073)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.573	0.573	0.572	0.529	0.529	0.528

Table 2 continued

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
			Panel C: Natural Log of Salary			
Rival Shock (T–2)	–0.025	–0.009	–0.008	0.006	0.003	0.006
	(–0.749)	(–0.246)	(–0.181)	(0.292)	(0.142)	(0.274)
Rival Shock (T–1)	–0.011	–0.037	–0.035	0.000	–0.005	–0.019
	(–0.355)	(–0.999)	(–0.834)	(0.013)	(–0.252)	(–0.782)
Rival Shock (T)	–0.042	–0.040	–0.029	0.020	0.029	0.008
	(–1.342)	(–0.998)	(–0.625)	(1.019)	(1.338)	(0.332)
Rival Shock (T+1)	0.038	0.079*	0.069	0.009	0.041	0.019
	(0.945)	(1.900)	(1.502)	(0.409)	(1.633)	(0.679)
Rival Shock (T+2)	–0.007	0.098**	0.103*	–0.011	0.034	0.051
	(–0.129)	(1.994)	(1.794)	(–0.370)	(1.072)	(1.501)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.621	0.622	0.622	0.334	0.334	0.334
			Panel D: Natural Log of Total Compensation			
Rival Shock (T–2)	–0.047	–0.051	–0.060	–0.048	–0.046	–0.048
	(–0.977)	(–0.946)	(–1.002)	(–1.593)	(–1.369)	(–1.267)
Rival Shock (T–1)	0.059	0.060	0.038	0.061**	0.074**	0.060
	(1.294)	(1.172)	(0.690)	(2.007)	(2.185)	(1.618)
Rival Shock (T)	–0.034	–0.024	–0.043	–0.020	–0.011	0.004
	(–0.718)	(–0.457)	(–0.780)	(–0.653)	(–0.311)	(0.112)
Rival Shock (T+1)	0.080	0.084	0.066	0.032	0.064*	0.034
	(1.512)	(1.453)	(1.028)	(0.898)	(1.697)	(0.818)
Rival Shock (T+2)	–0.062	–0.043	–0.051	–0.017	–0.043	–0.051
	(–0.916)	(–0.607)	(–0.645)	(–0.370)	(–0.884)	(–0.970)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.685	0.685	0.685	0.556	0.557	0.556

Table 3: Executive Compensation Fractions around BTD Events

The tests in this table examine the effect of afflicting BTD events on rival executive compensation percentages, relative to those of control firms. The table presents coefficients from OLS regressions that include firm-, calendar year-, and BTD event vintage year fixed effects, and cluster standard errors by firm. The dependent variables are indicated in the title of each panel and are calculated for each executive-year as the dollar amount of a compensation component divided by total compensation. The analysis sample, summarized in Table 1, consists of compensation records for 4,549 executives at 544 publicly listed firms from 2010 through 2019. These records correspond to 12,304 unique executive-firm-year observations. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event. *Rival Shock (T±N)* is an indicator defined at the firm–level and equals one in year *T±N* relative to the afflicting BTD year. Results in the first (last) three columns are reported from tests that use the sample of CEOs (all executives). t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Percentage of Stock Options						
Rival Shock (T–2)	–0.021	–0.017	–0.022	–0.020*	–0.015	–0.020
	(–1.211)	(–0.869)	(–0.994)	(–1.740)	(–1.132)	(–1.281)
Rival Shock (T–1)	0.033**	0.023	0.011	0.021*	0.014	0.005
	(1.966)	(1.246)	(0.544)	(1.801)	(1.069)	(0.361)
Rival Shock (T)	0.012	0.020	0.010	0.008	0.013	0.013
	(0.702)	(0.992)	(0.453)	(0.623)	(0.913)	(0.828)
Rival Shock (T+1)	0.053**	0.064***	0.066***	0.040***	0.050***	0.052***
	(2.525)	(2.777)	(2.634)	(2.736)	(3.236)	(2.903)
Rival Shock (T+2)	0.034	0.012	0.012	0.017	0.006	0.018
	(1.291)	(0.436)	(0.405)	(0.850)	(0.269)	(0.782)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.417	0.417	0.416	0.374	0.374	0.374

Table 3 continued

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
Panel B: Percentage of Stocks						
Rival Shock (T–2)	–0.012	–0.009	–0.014	–0.008	–0.006	–0.008
	(–1.047)	(–0.651)	(–0.922)	(–0.990)	(–0.607)	(–0.661)
Rival Shock (T–1)	–0.011	–0.007	0.004	–0.010	–0.005	0.007
	(–1.024)	(–0.578)	(0.257)	(–1.169)	(–0.503)	(0.629)
Rival Shock (T)	–0.017	–0.009	–0.009	–0.019**	–0.016*	–0.006
	(–1.518)	(–0.706)	(–0.628)	(–2.336)	(–1.702)	(–0.605)
Rival Shock (T+1)	–0.019	–0.016	–0.017	–0.025**	–0.018*	–0.016
	(–1.463)	(–1.135)	(–1.087)	(–2.437)	(–1.651)	(–1.397)
Rival Shock (T+2)	–0.005	0.013	0.005	–0.005	0.004	–0.005
	(–0.297)	(0.736)	(0.231)	(–0.379)	(0.318)	(–0.348)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.544	0.543	0.543	0.480	0.479	0.479
Panel C: Percentage of Salary						
Rival Shock (T–2)	0.028**	0.030**	0.025	0.028***	0.025**	0.023*
	(2.156)	(1.978)	(1.510)	(3.127)	(2.383)	(1.958)
Rival Shock (T–1)	–0.018	–0.022*	–0.014	–0.012	–0.020**	–0.019*
	(–1.517)	(–1.704)	(–0.921)	(–1.313)	(–2.099)	(–1.780)
Rival Shock (T)	0.007	–0.002	0.006	0.012	0.008	0.000
	(0.531)	(–0.123)	(0.421)	(1.332)	(0.820)	(0.026)
Rival Shock (T+1)	–0.023	–0.027*	–0.024	–0.015	–0.022**	–0.019
	(–1.616)	(–1.803)	(–1.451)	(–1.416)	(–2.040)	(–1.538)
Rival Shock (T+2)	–0.014	–0.005	–0.003	–0.013	–0.003	0.007
	(–0.830)	(–0.257)	(–0.156)	(–1.004)	(–0.205)	(0.449)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.476	0.476	0.475	0.412	0.411	0.411

Table 4: Summary Statistics for the Rival Risk-Taking Sample

This table reports summary statistics on the BTD rival indicators (Panel A) and the firm risk-taking variables (Panel B). The analysis sample consists of 544 firms that were publicly listed and reported executive compensation in at least one year from 2010 through 2019. The observation level of the sample is firm-year, and the final panel includes 3,118 observations. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. Afflicted rivals are firms that had significantly negative stock returns (more details below) around the announcement of a BTD award to a competitor in a therapeutic market where the rival was active. Control firms are either firms that have never experienced a BTD event in any of their markets, or firms that eventually experience a BTD event, but before or after the five-year window centered on the BTD event year, closes (if they do not experience another BTD event).

Panel A reports the average values of the afflicted rival-year indicators. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the afflicting BTD event. If a rival experiences multiple afflicting BTD events in consecutive years, then more than one rival-year indicator may equal one. For example, if a rival experiences two afflicting BTD events in 2014 and 2015, then for that rival's year 2013 observations a value of one is assigned to both indicators *Rival Shock (T–1)* (referencing the 2014 event) and *Rival Shock (T–2)* (referencing the 2015 event).

Panel B reports the averages, medians, and standard deviations of the risk-taking indicators. These variables are first constructed using the drug-level records in the Cortellis database, then aggregated to the firm-level. *Drug Initiation* is an indicator calculated each firm-year, and it is equal to one in the years when a firm starts developing a drug project for the first time. *New Technology Initiation* is an indicator that is equal to one in the years when a firm starts developing a drug project for the first time, and that new project uses a technology (i.e., target-based action) that the firm has not used before. *Lengthy Development Initiation* is an indicator equal to one in the years that a firm starts developing a new project for the first time, and that new project targets a therapeutic market that has an average development time above the median level in the Cortellis database. Development time is the average time spent by drug projects in a therapeutic market to complete clinical trials and receive FDA approval.

Panel A: Afflicted Rival-Year Indicators

	Lower Half	Lowest Tercile	Lowest Quartile
	(1)	(2)	(3)
Rival Shock (T–2)	0.143	0.095	0.071
Rival Shock (T–1)	0.158	0.105	0.079
Rival Shock (T)	0.153	0.102	0.075
Rival Shock (T+1)	0.108	0.072	0.054
Rival Shock (T+2)	0.074	0.047	0.034

Panel B: Risk-Taking Variables

	Mean	Median	Standard Deviation
	(1)	(2)	(3)
Drug Initiation	0.549	1.000	0.498
New Technology Initiation	0.296	0.000	0.456
Lengthy Development Initiation	0.382	0.000	0.486

Table 5: Firm Risk-Taking Activities around BTD Events

The tests in this table examine the effect of afflicting BTD events on the risk-taking activities of rivals, relative to those of control firms. The table presents coefficients from OLS regressions that include firm-, calendar year-, and BTD event vintage year fixed effects, and cluster standard errors by firm. The dependent variables are defined below. The analysis sample, summarized in Table 4, consists of 544 firms that were publicly listed and reported executive compensation in at least one year from 2010 through 2019. The observation level of the sample is firm-year, and the final panel includes 3,118 observations. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the afflicting BTD event.

In Panel A, the dependent variable, *Drug Initiation*, is an indicator equal to one in the years when a firm starts developing a drug project for the first time.

In Panel B, the dependent variable, *New Technology Initiation*, is an indicator equal to one in the years when a firm starts developing a drug project for the first time and that new project uses a technology (i.e., target-based action) that the firm has not used before.

In Panel C, the dependent variable, *Lengthy Development Initiation*, is an indicator equal to one in the years that a firm starts developing a new project for the first time and that new project targets a therapeutic market that has an average development time above the median level in the Cortellis database. Development time is the average time spent by drug projects in a therapeutic market to complete clinical trials and receive FDA approval.

t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	Median	Tercile	Quartile
	(1)	(2)	(3)
Panel A: Drug Initiations			
Rival Shock (T–2)	0.060*	0.060	0.050
	(1.836)	(1.639)	(1.258)
Rival Shock (T–1)	0.041	0.001	–0.024
	(1.242)	(0.017)	(–0.625)
Rival Shock (T)	0.028	0.030	0.064
	(0.737)	(0.743)	(1.466)
Rival Shock (T+1)	0.080**	0.078**	0.109**
	(2.202)	(2.014)	(2.438)
Rival Shock (T+2)	–0.023	0.008	0.021
	(–0.480)	(0.146)	(0.395)
Observations	3,090	3,090	3,090
R-squared	0.371	0.370	0.370

Table 5 continued

	Median (1)	Tercile (2)	Quartile (3)
Panel B: Drug Initiations using New Technology			
Rival Shock (T–2)	0.022	0.014	–0.028
	(0.680)	(0.383)	(–0.699)
Rival Shock (T–1)	0.018	–0.010	–0.031
	(0.536)	(–0.279)	(–0.830)
Rival Shock (T)	–0.027	0.010	0.012
	(–0.679)	(0.243)	(0.243)
Rival Shock (T+1)	0.010	0.103**	0.127***
	(0.276)	(2.437)	(2.622)
Rival Shock (T+2)	0.032	0.066	0.060
	(0.622)	(1.128)	(1.004)
Observations	3,090	3,090	3,090
R-squared	0.357	0.359	0.360
Panel C: Drug Initiations in Therapeutic Markets with Lengthy Development Times			
Rival Shock (T–2)	0.059*	0.022	0.007
	(1.773)	(0.566)	(0.168)
Rival Shock (T–1)	0.031	0.013	0.019
	(0.954)	(0.365)	(0.483)
Rival Shock (T)	–0.031	–0.032	–0.020
	(–0.826)	(–0.764)	(–0.420)
Rival Shock (T+1)	0.066*	0.103**	0.108**
	(1.744)	(2.547)	(2.223)
Rival Shock (T+2)	–0.039	–0.005	–0.006
	(–0.726)	(–0.080)	(–0.100)
Observations	3,090	3,090	3,090
R-squared	0.368	0.367	0.367

Table 6: Compensation Robustness Tests using only the First BTD Events Experienced by Rivals

The tests in this replicate those reported in Table 2 using the alternative afflicting BTD rival-year indicators that are defined using only the first afflicting BTD events. The table presents coefficients from OLS regressions that include firm-, calendar year-, and BTD event vintage year fixed effects, and cluster standard errors by firm. The dependent variables are indicated in the title of each panel and are computed for each executive-year as the natural log of each compensation component. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the first afflicting BTD event year, where *T–2* identifies the second year before the first afflicting BTD event, *T+2* identifies the second year after the first BTD event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the first afflicting BTD event. Results in the first (last) three columns are reported from tests that use the sample of CEOs (all executives). The compensation (rival-year indicator) variables are described in Table 1 (Table 6). t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Natural Log of Stock Options					
Rival Shock (T–1)	0.447	0.170	–0.025	0.369	0.060	–0.045
	(1.304)	(0.486)	(–0.063)	(1.439)	(0.228)	(–0.143)
Rival Shock (T)	–0.379	–0.395	–0.026	–0.409	–0.419	–0.160
	(–1.072)	(–0.996)	(–0.060)	(–1.550)	(–1.344)	(–0.448)
Rival Shock (T+1)	0.352	0.925**	1.173**	0.399	0.941***	1.136***
	(0.825)	(2.105)	(2.438)	(1.268)	(2.883)	(3.038)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.404	0.404	0.405	0.348	0.348	0.349
	Panel B: Percentage of Stock Options					
Rival Shock (T–1)	0.031*	0.017	0.006	0.024**	0.013	0.002
	(1.825)	(0.942)	(0.283)	(2.063)	(1.002)	(0.163)
Rival Shock (T)	–0.001	0.003	–0.006	–0.002	0.001	–0.002
	(–0.036)	(0.149)	(–0.295)	(–0.192)	(0.081)	(–0.108)
Rival Shock (T+1)	0.033	0.059**	0.068***	0.021	0.041**	0.051***
	(1.514)	(2.518)	(2.640)	(1.421)	(2.492)	(2.779)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.417	0.416	0.417	0.374	0.374	0.374

Table 7: Compensation Robustness Tests using Alternative Definition of Afflicted Rivals

The tests in this replicate those reported in Table 2 using the alternative afflicting BTD rival-year indicators based on a combination of the CARs used earlier and the fractions of the rival's projects that are in the shocked product markets. The table presents coefficients from OLS regressions that include firm-, calendar year-, and BTD event vintage year fixed effects, and cluster standard errors by firm. The dependent variables are indicated in the title of each panel and are computed for each executive-year as the natural log of each compensation component. The sample excludes the observations of BTD-awarded firms from the first award year to the end of the sample period. The sample includes two types of firms: afflicted rivals and control firms. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years *and* a fraction of projects that is in the shocked product market that is in either the higher half ("Median"), highest tercile ("Tercile"), or highest quartile ("Quartile"). Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the first afflicting BTD event year, where *T–2* identifies the second year before the first afflicting BTD event, *T+2* identifies the second year after the first BTD event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the first afflicting BTD event. Results in the first (last) three columns are reported from tests that use the sample of CEOs (all executives). The compensation (rival-year indicator) variables are described in Table 1 (Table 6). t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	CEO Sample			All Executives Sample		
	Median	Tercile	Quartile	Median	Tercile	Quartile
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Natural Log of Stock Options						
Rival Shock (T–1)	0.477	0.650	0.371	0.405	0.417	0.362
	(1.212)	(1.491)	(0.746)	(1.427)	(1.285)	(0.936)
Rival Shock (T)	0.053	–0.235	0.276	–0.033	–0.312	0.234
	(0.137)	(–0.484)	(0.525)	(–0.109)	(–0.851)	(0.574)
Rival Shock (T+1)	0.950**	1.279***	1.532***	0.888***	1.261***	1.335***
	(2.219)	(2.635)	(2.785)	(2.788)	(3.334)	(3.077)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.402	0.403	0.403	0.346	0.347	0.347
Panel B: Percentage of Stock Options						
Rival Shock (T–1)	0.022	0.032	0.016	0.021	0.026	0.016
	(1.101)	(1.394)	(0.601)	(1.472)	(1.636)	(0.908)
Rival Shock (T)	0.014	0.009	0.014	0.009	0.002	0.019
	(0.688)	(0.375)	(0.558)	(0.636)	(0.139)	(1.016)
Rival Shock (T+1)	0.042*	0.070***	0.081***	0.032**	0.061***	0.062***
	(1.863)	(2.597)	(2.626)	(1.961)	(3.112)	(2.749)
Observations	2,990	2,990	2,990	12,304	12,304	12,304
R-squared	0.415	0.416	0.416	0.374	0.374	0.374

Table 8: Rival Risk-Taking Robustness Tests using only the First BTD Events Experienced by Rivals

The tests in this table replicate those of Table 5 using the alternative afflicting BTD rival-year indicators that are defined using only the first afflicting BTD events. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years. Control firms are either firms that have never experienced a BTD event in any of their markets, or firms that eventually experience a BTD event, but before or after the five-year window centered on the BTD event year, closes (if they do not experience another BTD event). The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the afflicting BTD event.

In Panel A, the dependent variable, *Drug Initiation,* is an indicator equal to one in the years when a firm starts developing a drug project for the first time.

In Panel B, the dependent variable, *New Technology Initiation,* is an indicator equal to one in the years when a firm starts developing a drug project for the first time and that new project uses a technology (i.e., target-based action) that the firm has not used before.

In Panel C, the dependent variable, *Lengthy Development Initiation,* is an indicator equal to one in the years that a firm starts developing a new project for the first time and that new project targets a therapeutic market that has an average development time above the median level in the Cortellis database. Development time is the average time spent by drug projects in a therapeutic market to complete clinical trials and receive FDA approval.

t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	Median	Tercile	Quartile
	(1)	(2)	(3)
Panel A: Drug Initiations			
Rival Shock (T–1)	0.062	0.020	–0.021
	(1.386)	(0.436)	(–0.434)
Rival Shock (T)	0.052	0.056	0.091*
	(1.018)	(1.073)	(1.730)
Rival Shock (T+1)	0.098**	0.101**	0.126**
	(1.981)	(2.024)	(2.398)
Observations	3,090	3,090	3,090
R-squared	0.373	0.372	0.373
Panel B: Drug Initiations using New Technology			
Rival Shock (T–1)	0.069	0.010	–0.013
	(1.586)	(0.221)	(–0.286)
Rival Shock (T)	–0.002	0.047	0.054
	(–0.033)	(0.921)	(0.962)
Rival Shock (T+1)	0.043	0.161***	0.165***
	(0.892)	(3.166)	(3.054)
Observations	3,090	3,090	3,090
R-squared	0.365	0.367	0.368
Panel C: Drug Initiations in Therapeutic Markets with Lengthy Development Time			
Rival Shock (T–1)	0.045	0.017	0.020
	(0.987)	(0.360)	(0.409)
Rival Shock (T)	–0.010	0.012	0.031
	(–0.199)	(0.236)	(0.585)
Rival Shock (T+1)	0.061	0.091*	0.091*
	(1.226)	(1.793)	(1.675)
Observations	3,090	3,090	3,090
R-squared	0.371	0.370	0.370

Table 9: Rival Risk-Taking Robustness Tests using Alternative Definition of Afflicted Rivals

The tests in this table replicate those of Table 5 only using the alternative afflicting BTD rival-year indicators based on a combination of the CARs used earlier and the fractions of the rival's projects that are in the shocked product markets. The column headings indicate whether an afflicted rival has an announcement return around a BTD event that is in either the lower half ("Median"), lowest tercile ("Tercile"), or lowest quartile ("Quartile") of all rival announcement returns around all BTD events in all years *and* a fraction of projects that is in the shocked product market that is in either the higher half ("Median"), highest tercile ("Tercile"), or highest quartile ("Quartile"). Control firms are either firms that have never experienced a BTD event in any of their markets, or have experienced a BTD event but were not afflicted by it, or are firms that were afflicted by a BTD event, but this occurred before or after the five-year window centered on the BTD event year. The subscript *T* indexes the afflicting BTD event year, where *T–2* identifies the second year before the BTD event, *T+2* identifies the second year after the event, and so on. *Rival Shock (T±N)* is an indicator defined at the firm-level and equals one in year *T±N* relative to the year the rival experienced the afflicting BTD event.

In Panel A, the dependent variable, *Drug Initiation*, is an indicator equal to one in the years when a firm starts developing a drug project for the first time.

In Panel B, the dependent variable, *New Technology Initiation*, is an indicator equal to one in the years when a firm starts developing a drug project for the first time and that new project uses a technology (i.e., target-based action) that the firm has not used before.

In Panel C, the dependent variable, *Lengthy Development Initiation*, is an indicator equal to one in the years that a firm starts developing a new project for the first time and that new project targets a therapeutic market that has an average development time above the median level in the Cortellis database. Development time is the average time spent by drug projects in a therapeutic market to complete clinical trials and receive FDA approval.

t-statistics are reported in parentheses. Asterisks indicate statistical significance as follows: *** p<0.01, ** p<0.05, * p<0.1.

	Median	Tercile	Quartile
	(1)	(2)	(3)
Panel A: Drug Initiations			
Rival Shock (T–1)	0.015	–0.021	–0.007
	(0.382)	(–0.489)	(–0.158)
Rival Shock (T)	0.016	0.063	0.096
	(0.389)	(1.365)	(1.580)
Rival Shock (T+1)	0.049	0.054	0.116**
	(1.199)	(1.183)	(2.128)
Observations	3,090	3,090	3,090
R-squared	0.368	0.368	0.369
Panel B: Drug Initiations using New Technology			
Rival Shock (T–1)	–0.011	–0.014	–0.011
	(–0.299)	(–0.330)	(–0.260)
Rival Shock (T)	–0.010	0.037	0.041
	(–0.245)	(0.753)	(0.768)
Rival Shock (T+1)	0.034	0.080*	0.120**
	(0.784)	(1.678)	(2.248)
Observations	3,090	3,090	3,090
R-squared	0.361	0.362	0.363
Panel C: Drug Initiations in Therapeutic Markets with Lengthy Development Time			
Rival Shock (T–1)	0.018	–0.025	0.032
	(0.478)	(–0.571)	(0.656)
Rival Shock (T)	–0.026	–0.007	0.015
	(–0.629)	(–0.149)	(0.287)
Rival Shock (T+1)	0.070	0.088*	0.136**
	(1.622)	(1.883)	(2.422)
Observations	3,090	3,090	3,090
R-squared	0.367	0.367	0.368