Competition and R&D Financing Decisions: Evidence from the Biopharmaceutical Industry*

Richard T. Thakor† and Andrew W. Lo‡

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Abstract

How does competition affect innovation and how it is financed in R&D-intensive firms? We study the interaction between competition, R&D investments, and the financing choices of such firms using data on biopharmaceutical firms. To motivate the empirical hypotheses, we develop a model for such firms in which their capital structure and amounts invested in R&D as well as existing assets are all determined in response to the degree of competition in the industry. The key predictions are that, as competition increases, such firms will: (1) increase R&D investment relative to investment in assets-in-place that support existing products; (2) carry more cash and maintain less net debt; and (3) experience declining betas but greater total stock return volatility due to higher idiosyncratic risk. While the focus is on the biopharmaceutical industry, the results are broadly applicable to other R&D-intensive industries as well. We provide empirical support for these predictions. In order to deal with the endogeneity issue introduced by the fact that a firm's R&D investments and the product-market competition it faces influence each other, we provide further evidence through a differences-in-differences analysis.

Keywords: Healthcare Finance; Pharmaceutical Industry; Biotechnology Industry; Capital Structure; R&D Investments; Competition

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†MIT Sloan School of Management, 100 Main Street, E62-615, Cambridge, MA 02142

‡MIT Sloan School of Management, CSAIL, and NBER, 100 Main Street, E62–618, Cambridge, MA 02142

1 Introduction

The idea that innovation is a key to economic growth has a long tradition, dating back at least to Adam Smith, who explicitly recognized the role of technological progress in the production function of the firm. Competition also grows with the economy, and since monopolists are unlikely to perceive the same benefits from innovation that competitive firms perceive (see, for example, Aghion, Bloom, Blundell, and Griffith (2005)), a natural question that arises is: how does competition affect innovation? In addition, investments in R&D that make innovation possible often require large amounts of capital that must be externally financed, so financing frictions and the risk profile of the firm can affect innovation as well (e.g. Hall and Lerner (2010), and Cornaggia et. al. (2013)). Since firms can be expected to seek financing through the lowest-cost means, a second important question that arises is: how does product-market competition affect the financing choices and risk profiles of firms through its effect on their innovation incentives? That is, it is important to study how financing and competition interact, and the important role that this interaction plays for R&D-intensive firms, which are crucial drivers of innovation.

The primary goal of this paper is to provide an empirical answer to these questions. While each of the two questions stated above has been studied separately, we are not aware of any paper that has studied the relationship between competition, innovation, financing, and risk in an integrated framework. We first develop a simple (reduced-form) theoretical model to provide motivation for a number of testable hypotheses. We then provide empirical evidence on the relationship between competition, R&D investment, financing, and the evolution of the firm's risk profile by studying the biopharmaceutical (biopharma) industry.

Apart from the fact that this industry is intimately tied to health care—a sector that is now one-fifth of the U.S. economy—R&D is the lifeblood of biopharma firms, and spending on R&D often dwarfs spending on property, plant, and equipment. Moreover, decisions related to capital budgeting and financing for R&D that these firms make depart sharply from those made for other capital projects, due to the high-risk, staged nature of R&D investment and

the absence of observable post-investment cash flows for many years. This makes it difficult to simply extrapolate the insights on financing choices for other kinds of firms to R&D-intensive firms like those in biopharma (see Myers and Howe (1997), who lay out these issues for the pharmaceutical industry). Moreover, this industry has become increasingly competitive over time for a variety of reasons, including regulation, lower costs of entry due to improvements in technology, and the expiration of patents combined with high development costs of new therapeutics (e.g. Caves, Whinston, and Hurwitz (1991), Grabowski and Vernon (1992), and others). These factors have squeezed margins from existing products associated with assets-in-place, with marked implications for R&D investments in new products as well as the capital structure choices of these firms.[1] These developments, coupled with the R&D-intensive nature of these firms, make the biopharma industry well suited for the study of the two questions posed above.

We examine how an R&D-intensive firm makes decisions about investment (how much to invest in R&D and how much to invest in assets in place), capital structure, and cash to carry, and how these decisions are affected by the mediating influence of its competitive environment. We start by developing a simple theoretical model whose main goal is to motivate and deliver testable predictions. The model is in reduced form in order to get to the predictions as directly as possible. The first prediction of the model is that greater product-market competition induces the firm to cut back on investments in assets-in-place and increase investments in R&D. The intuition is similar to the "escape-the-competition" effect (e.g. Aghion , Bloom, Blundell, and Griffith (2005))—increased competition erodes margins on existing products, thus making them less attractive relative to new R&D products

[1]For example, the expiration of a patent and the subsequent entry of a generic drug in the marketplace. Another factor is the rapid improvement in technology in the past decades, which has allowed many competitors to enter the marketplace and offer products that directly compete with many long-established firms. The implications of these developments are potentially pervasive. For example, see Bloom, Schankerman, and Van Reenan (2013), who examine the effects of R&D spillovers, which may be either positive (due to improvements in knowledge and technology) or negative (due to business competition). Also, see Kogan and Papanikolaou (2010, 2014), who model the effects technology shocks on assets-in-place and growth opportunities, and derive macroeconomic and asset pricing implications. And Haddad, Ho, and Loualiche (2014) explore the impact of disagreement about the details of R&D on competition, which can lead to innovation booms.

that are under patent protection.

The second prediction of the model is that firms will carry more cash and net debt will decline in response to greater product market competition. The reason is that greater competition leads to more investments in R&D, which, in turn, makes debt financing less attractive because the R&D becomes substantially less profitable to the firm if debtholders can force the firm to repay early, thereby causing premature liquidation of the (illiquid) R&D. The reason for carrying extra cash is to avoid having to raise future financing in states of the world in which such financing may be unavailable but is viewed as being valuable by firm insiders. The relatively large cash balances of R&D-intensive companies are consistent with this implication.

The final prediction of the model follows from the first prediction. Since existing products have systematic risk, whereas (at least early-stage) R&D has mainly idiosyncratic risk (see Pastor and Veronesi (2005)), the reallocation of investments from assets-in-place to R&D that is induced by increased competition causes systematic risk in the firm to decline. Moreover, competition causes idiosyncratic risk in R&D to *increase* over time, so the shift in stock returns from systematic to idiosyncratic risk is accompanied by an *increase* in total stock return volatility.

With regard to investment, while the majority of the analysis focuses on the choice between investing in assets-in-place versus new early-stage in-house R&D, in reality, an R&D-intensive firm may also be able to choose a later-stage R&D investment outside of the firm, through acquisition or collaboration. For example, it is common for a pharmaceutical company to acquire a smaller biotech company in order to gain access to its portfolio of R&D projects that are in the later stages of development. In order to incorporate this aspect into the analysis, we include a simple extension of the main model in which the biopharma firm has a choice of R&D projects: either do R&D in-house ("internal" R&D) or acquire a biotech company with an R&D project that has already succeeded ("external" R&D). While there is a large theoretical and empirical literature on the R&D boundaries of the firm related to the

choice between internal and external R&D, our goal is to simply connect this R&D choice to the analysis in this paper, and to demonstrate how the analysis may change when such a choice is open to firms.[2]

Using data on publicly traded biopharma companies from 1950 to 2012, we provide strong empirical support for these predictions. We first provide time-series evidence, taking as a given the increase in competition over time which has been documented in previous research. We document that R&D and cash holdings of the firms in the sample are substantial, and have increased over time in response to increasing competition. In particular, for the average biopharma firm, R&D as a percentage of total assets increased from roughly 3% in 1950 to 46% in 2012, whereas cash as a percentage of total assets increased from 22% in 1950 to 55% in 2012. In addition, assets-in-place and net debt as a percentage of total assets declined for the average biopharma firm as competition increased. Moreover, we show that the betas of a value-weighted portfolio of biopharma firms have declined over time—for example, the market beta of the industry has declined from over 1.0 in 1950 to approximately 0.7 in 2012. Finally, idiosyncratic and total stock return volatility for biopharma firms have increased while competition has increased.

While this time-series evidence is consistent with the predictions of our model, it is also subject to potential endogeneity concerns. In particular, biopharma firms face competition that has both endogenous and exogenous elements. The endogenous competition is affected by how much the firm spends on R&D (the more it spends, the lower the competition ceteris paribus). The exogenous nature of competition comes from things like changes market structure, regulation, and the nature of patent protection—developments that are plausibly exogenous at least at the individual firm level. To deal with these endogeneity concerns and provide causal evidence of the impact of competition on the variables we study, we exploit the quasi-natural experiment represented by a legislative change that induced an exogenous increase in competition in the biopharma industry: the Hatch-Waxman Act of 1984. This

[2]See Bhattacharya and Guriev (2004), Bhattacharya, Glazer, and Sappington (1990), Pisano (1990), Gans and Stern (1997), and Cassiman and Veugelers (2006), among others.

legislation made it significantly easier for generic drugs to compete with patented drugs and has been widely regarded as an act that increased competition in the industry (e.g. Grabowski and Vernon (1986, 1992)). Using a differences-in-differences approach, we again find strong supporting evidence for the main predictions of the model.

Our paper is related to the theoretical industrial organization literature that explores the effect of competition on innovation. For example, a number of papers have shown that innovation may allow the firm to differentiate its products more effectively, thereby generating an "escape-the-competition" effect (Aghion, Harris, Howitt, and Vickers (2001), and Aghion et. al. (2005)) that implies that competitive firms will tend to innovate more than a monopolist via the so-called "replacement effect" (Tirole (1988)). Aghion et. al. (2005) build a model where firms facing large competitive pressures may innovate in order to regain lost profit margins, but this effect may be reversed in industries where competition is less intense and laggard firms face large costs to catch up to industry leaders. Aghion, Dewatripont and Rey (1999) reach a similar conclusion based on the logic that competition can stimulate R&D by reducing expected bankruptcy costs. Recently, Aghion, Bechtold, Cassar and Herz (2014) have provided evidence based on lab experiments. They find that higher competition among product-market competitors leads to higher R&D by neck-and-neck firms and lower R&D by laggards.[3] While our paper also predicts that an increase in competition will increase innovation (through increased R&D investment), our model differs from Aghion et. al. (2005) and other studies in that we also focus on how competition affects the firm's choice of funding for innovation and its risk profile. Since a firm's ability to secure capital is crucial for undertaking R&D, we thus treat competition as an important determinant of innovation by considering its effect on the firm's interactions with the capital market and its risk characteristics.

[3]Other authors have also made the point that patentable innovation is one way for firms to protect against profit erosion induced by competition. For example, Langinier and Moschini (2002) note that the duration of a patent can affect the length of time the holder can exert monopoly power. See also Grant and Jordan (2015).

Our model is also related to the literature exploring the financing of R&D.[4] Hall and Lerner (2010) show that large firms prefer internal funds for financing R&D, whereas small firms experience high external financing costs that are only partially mitigated by venture capital. Brown, Fazzari, and Petersen (2009) empirically document a positive relationship between financing supply and R&D. Bergemann and Hege (2005) develop a theoretical model in which they examine how the choice of relationship versus arms-length financing by borrowers affects their R&D funding. While these papers focus on issues related to R&D financing, they do not consider the effect of product market competition on how R&D is financed. More recently, a handful of papers have explored how competition affects firms' innovation incentives and cash holdings. Lyandres and Palazzo (2014) show theoretically and empirically that the firms that successfully innovate use cash as a commitment device for implementation of successful innovations. Morellec, Nikolov, and Zucchi (2014) develop a dynamic model and provide empirical support that competition increases corporate cash holdings and equity issues. Our analysis differs from these studies in a number of ways. First, unlike these studies, we examine how the firm's optimal capital structure changes in response to competition. The cash decision is just one component of this capital structure decision. Second, we also examine how the firm's risk profile changes as competition induces a change in the mix of investment across R&D and assets-in-place, and in its capital structure. Furthermore, we provide clear empirical evidence that overcomes endogeneity concerns using data from the biopharmaceutical industry.

Our results are also related to an empirical literature that examines the R&D costs, returns, and risks in the pharmaceutical industry. For example, Grabowski and Vernon (1990) and DiMasi, Grabowski, and Vernon (1995) examine a selection of drugs introduced in the U.S. and show a substantial increase in competition and a skewed distribution of sales returns from the drugs. DiMasi, Hansen, and Grabowski (2003) examine the cost

[4]Our work is also related to the vast capital structure literature, e.g. Jensen and Meckling (1976), Myers and Majluf (1984), Stulz (1990), Zwiebel (1996), Abel (2014); see Graham and Leary (2011) and Myers (2001) for comprehensive reviews.

of new drug development. Ellison, Cockburn, Griliches, and Hausman (1997) model the demand for pharmaceutical products and compute price elasticities. Myers and Howe (1997) build a Monte Carlo life-cycle model of drug R&D development for the pharmaceutical industry, and examine the model's estimates of risk, return, NPV, and cost of capital. Gans, Hsu, and Stern (2002) and Gans and Stern (2003) look more generally at R&D-intensive firms, and examine how their R&D strategies are affected by competition and cooperation. Our paper is complementary to some of the evidence provided in these studies, but also provides additional empirical evidence focused on financial characteristics. Moreover, we focus explicitly on the interaction between competition, R&D spending, and capital structure decisions of biopharma companies which, to our knowledge, has not been considered in previous studies.

In Section 2 we describe our theoretical framework, and the main predictions it generates. We discuss the underlying economic intuition for the results, relegating the formal development and analysis of the model to the Appendix. We present the time-series evidence on average trends in Section 3, and the differences-in-differences analysis using the Hatch-Waxman Act as a source of exogenous variation is described in Section 4. We conclude in Section 5 and provide supplemental results in the Appendix.

2 Formulating Testable Hypotheses

In this section, we provide a sketch of a simple theoretical model, as well as the intuition for the results and predictions that it generates, to motivate the testable hypotheses we consider in our empirical analysis. We provide the full formal model in the Appendix, including proofs of the results.

2.1 The Model

We consider a large biopharmaceutical firm in a three-date model in which final payoffs occur at $t = 2$. The firm decides at date $t = 0$ how much to invest in R&D, how much to invest in assets-in-place, and its capital structure.

If the firm invests in R&D, the R&D consists of two stages. The initial R&D investment at $t = 0$ is for first-stage research. At $t = 1$, it will be known whether the first-stage research failed, was modestly successful, or was very successful. At this stage, R&D produces no cash flows, but allows the possibility of further investment. If the first-stage research was successful, the firm must decide whether to invest in second-stage R&D. Such a setup captures the staged R&D investment in biopharma firms in which a drug is considered a "success" if it passes Phases 1–3 of clinical trials, where each phase requires an additional investment. At $t = 2$, if the firm invested in both first-stage and second-stage research, the R&D produces a stochastic cash flow. The R&D produces both benefits that can be contracted upon with outside financiers—such as commercializable products—as well as benefits (such as knowledge generation) for insiders that cannot be contracted upon. If the firm invests in assets-in-place, they produce a positive cash flow at $t = 2$ that varies depending on competition (described below) and the state of the economy.

As in Pastor and Veronesi (2009), we assume that the risk associated with R&D is idiosyncratic and the risk associated with assets-in-place is systematic. By definition, R&D involves new projects that are one-off stand-alone investments by individual firms, and hence uncorrelated with the economy. Existing products involve similar investments by many other firms, and hence contain systematic risk. For example, in the biopharma industry, new drugs have patent protection and are thus less affected by investments by other firms due to the monopoly that patents confer on the specific drug (e.g. Langinier and Moschini (2002)). In contrast, existing products include generic drugs that no longer enjoy patent protection and are sensitive to the investments of other firms. This is also consistent with previous studies that have established that greater monopoly power is associated with a lower degree

of systematic risk (e.g. Subrahmanyam and Thomadkis (1980), Lee, Liaw, and Rahman (1990), and others).

At $t = 0$, the firm makes its capital structure decision, which involves determining the mix of debt and equity with which to finance the firm and how much excess cash to carry to date $t = 1$. At $t = 1$, the firm can again choose to raise capital. We assume that external financing for the second-stage R&D cannot be raised at $t = 1$ if the first-stage research failed or was only modestly successful.[5] However, insiders would like to fund the second-stage R&D even if the first-stage research has been only modestly successful, because of the non-contractible benefits to insiders.

The firm's cash flows are taxable, debt repayments are tax-deductible, and the firm operates in an adverse-selection environment in that there are observationally-identical lemons that also raise financing at $t = 0$. These lemon firms, while appearing identical to viable good firms, do not have the ability to produce cash flows from their R&D. At $t = 1$, the firm's bondholders receive a noisy signal that enables them to update their priors on whether the firm is good or a lemon. If a firm is suspected of being a lemon based on the signal, bondholders will demand to be repaid at $t = 1$—this leads to liquidation, since the firm has no cash flows at the interim date.[6] Thus, debt has a monitoring role in reducing misappropriation of resources, in line with theories of debt discipline extensively discussed in the literature (e.g. Hart and Moore (1995, 1998), Jensen (1986), and Calomiris and Kahn (1991)). Since the signal is noisy, the probability of a good firm being liquidated is positive.

Competition is modeled as a probability that a competing firm will arrive. If it does arrive, the firm engages in competition with the incumbent firm, driving down the cash flows on

[5]This assumption is consistent with the empirical evidence of Grabowski and Vernon (1990), who document a skewed distribution of returns for drugs in the marketplace, with "blockbuster" drugs achieving much higher returns than other drugs. Given the large investment costs of drug development (e.g. DiMasi and Grabowski (2007)), a very successful commercial result is often needed in order for the project to be perceived as positive NPV.

[6]The debt need not be viewed as short-term debt, but could be long-term debt where bondholders detect a covenant violation at the interim date and demand repayment then, or where there is an interest payment that bondholders have the option of forgiving until a later date.

its assets-in-place.[7] R&D, when successful, is patent-protected and thus unaffected by competitive entry. For example, one of the reasons why firms in the biopharma industry engage in R&D is to replace old drugs (many of which may be off-patent and thus face competitive pressures) with new drugs (which are patent-protected and insulated from competition).[8]

A time-line of the events of the model is given in *Figure 1.*

2.2 Intuition

The model allows us to characterize the firm's optimal investments in R&D and assets-in-place, and examine how these respond to competition. We show that higher competition causes investments in assets-in-place to decline and investments in R&D to increase, so R&D grows relative to assets-in-place. The intuition lies in the patent-protected rents that successful R&D offers the firm. An increase in competition erodes the payoffs of assets-in-place (since existing products are not under patent protection), which makes the payoffs from investment in R&D relatively more attractive. The firm then has an incentive to shift investment away from assets-in-place and towards R&D.[9]

The firm's capital structure decision trades off tax benefits against the possible loss of R&D rents if the (good) firm is erroneously liquidated at $t = 1$. The presence of lemons makes such early repayment/liquidation subgame perfect for the bondholders, even though

[7]The effect of competition here is the same as in Bertrand competition, where the two firms will reduce their prices down to their marginal costs. In our model, competition can be interpreted as structural changes in the industry or other changes in competition that are exogenous to the individual firm. Important drivers of competition to industries such as biopharma are exogenous technology or regulatory shocks that lower entry costs. For example, the Human Genome Project represented a technology shock that was plausibly exogenous to any individual firm's decision, and it led to the entry of numerous small biotech firms into the industry (see Thakor et. al. (2015)). Another example is the Hatch-Waxman Act, which was a source of exogenous variation in competition for the biopharma industry, and something we use for identification purposes later in our analysis. However, since R&D by incumbents can also affect the degree of competition, some portion of the degree of competition is endogenous (e.g. Gans and Stern (2000)). Our empirical tests are designed to tackle this potential endogeneity.

[8]This is consistent with the earlier cited literature, e.g. Tirole (1988), Langinier and Moschini (2002), and Grant and Jordan (2015). The specific way we have described competition is not critical to our prediction. All that is needed is that the firm's profit margins on patentable drugs emerging from R&D are higher than those from existing products that do not enjoy patent protection.

[9]In the terminology of Aghion et. al. (2005), we are modeling "neck-and-neck" firms competiting in the product market.

$t = 0$	$t = 1$	$t = 2$
• Firm determines its capital structure as well as scale, i.e., how much to invest in assets-in-place (or existing products) and how much to invest in R&D. Investment capital is raised externally from investors in an environment of adverse selection. • With some probability, a competitor arrives, which reduces the profitability of existing products • Firm makes its investment in existing products and its first-stage investment in R&D	• The state of the economy (which will determine date-2 payoffs of assets that covary with the economy) is revealed. • Bondholders receive noisy information about the quality of the firm and can demand repayment on debt. • Information is revealed about the success of the first-stage R&D. The firm may need to raise additional financing to fund its second-stage R&D.	All payoffs on existing assets and R&D are realized. Shareholders and bondholders are paid off.

Figure 1: Time-line of Decisions

it is costly for them. We show that as competition increases, debt financing declines in the firm's capital structure. The intuition is twofold. First, since the firm reduces its investment in assets-in-place, it reduces its collateral base, which makes it unable to support as much debt. Second, given the firm's larger investment in R&D in response to increased competition, the possible loss of R&D rents due to erroneous liquidation at $t = 1$ is greater.

We also show that the potential lack of access to external second-stage R&D funding at $t = 1$ when the firm's insiders want to invest causes the firm to carry excess cash from $t = 0$ to $t = 1$. This is because there is a future state of the world (when the first-stage R&D is modestly successful) in which outside investors will be unwilling to fund second-stage R&D even though the firm's insiders consider it valuable to do so due to non-contractible R&D rents.[10] Since the amount of second-stage funding is positively related to the investment in first-stage R&D, the higher relative investment in R&D in response to higher competition also means that the firm carries more excess cash as competition increases. This result is similar to a precautionary demand for liquidity in anticipation of future states in which there may be a shortfall (see, for example, Bolton, Chen, and Wang (2014)).

The excess cash that the firm holds, combined with the earlier result about lower debt financing, means that the firm's *net debt* will fall as it faces higher competition. Finally, since the firm shifts its investments from assets-in-place (which carries systematic risk) to R&D (which carries idiosyncratic risk) in response to higher competition, an increase in competition also implies that the firm's beta will decline as competition increases. By the same token, the firm's idiosyncratic risk will also increase. Since R&D investments tend to be riskier than other types of investment (e.g. DiMasi, Hansen, Grabowski, and Lasagna (1991)), this also implies that the firm's total stock return volatility will tend to increase.

As an extension of the model, we also examine the firm's choice between doing in-house R&D and buying a firm (such as a smaller biotech firm) that has successfully completed first-

[10] An alternative interpretation of this result is that the firm's insiders have information about the quality of the R&D that they cannot credibly communicate to investors, and therefore investors are unwilling to provide additional funding.

stage research. We find that firms with relatively lower R&D success rates will tend to acquire other firms that rely on "internal" R&D. It follows that an increase in competition will induce firms to engage in more "external" R&D via acquisitions. Moreover, since "external" R&D (i.e. acquiring a firm) involves less risk than internal R&D, one would expect acquiring firms' stock returns to have lower idiosyncratic risk than the stock returns of firms that engage in internal R&D. We leave tests of these predictions of the extended model to future research.

2.3 Empirical Implications

To summarize, our model has implications for how the characteristics of R&D-intensive biopharma firms change in response to changes in competition. A number of studies have documented increased competition in the biopharma industry, brought about by a combination of improvements in technology and entry of generic drugs. For example, the Drug Price Competition and Patent Term Restoration Act of 1984 (informally known as the Hatch-Waxman Act) and the Generic Initiative for Value and Efficiency of 2007 were designed to increase the entry of generic drugs into the market place in order to spur competition (see Caves, Whinston, and Hurwitz (1991), Grabowski and Vernon (1990, 1992), and others for more details). Consistent with this evidence, we also document in the empirical results an increase in competition over time, as viewed through various measures. The model predicts that, as competition increases:

1. Firms will increase R&D investment and reduce investment in assets-in-place that support existing products.

2. Firms will carry more cash and net debt will decline.

3. Firm betas will decline, but idiosyncratic risk will rise. Under some conditions, total stock return volatility will rise.

3 Time-Series Evidence

To test the empirical implications of our model of R&D-intensive corporate financial policies, we first consider time-series evidence on increasing competition in the biopharma industry and then turn to the predictions of the model for R&D investments, assets-in-place, capital structure, cash balances, and risk. The empirical evidence is generally consistent with the theory's predictions.

While the time-series evidence is suggestive of the effects documented by our model, it is subject to endogeneity concerns, as its interpretation implicitly requires competition in the biopharma industry to be exogenous. However, this assumption is unlikely to hold for the biopharma industry. For example, R&D outlays by incumbent firms can act as a competitive entry barrier—in other words, R&D is affected by competition, but competition is also affected by R&D. To overcome this endogeneity problem, we exploit the exogenous variation introduced by the passage of the Drug Price Competition and Patent Term Restoration Act of 1984, and conduct a differences-in-differences analysis to provide a cleaner empirical test of the model.

3.1 Empirical Methodology

We begin by documenting evidence of how competition in the biopharma industry has increased over time, consistent with the results of other studies. We first measure competition through the Concentration Ratio, which is defined as the market share of the largest firms in the industry. It is defined as follows for each year t:

$$CR_t(M) = \sum_{i=1}^{M} s_{i,t}, \tag{1}$$

where s_i is the market share of firm i, defined as the proportion of the industry's sales that are attributable to firm i. A lower value of $CR_t(M)$ in a given year indicates less concentration, and thus greater competition, in the industry. As is common, we calculate

(1) for $M = 4$ (4-firm Concentration Ratio).[11] However, for the biopharma industry, many small biotech firms compete with larger firms through their R&D efforts, even though they may not have products that are commercialized (and therefore have little to no sales). In addition, since the FDA approval process for drugs is lengthy, new competing firms may not have an effect on industry sales until several years after they enter. Therefore, sales-based measures of competition such as the Concentration Ratio may not fully capture changes in competition for the biopharma industry. As a result, we also measure competition in a more simple manner as a robustness check, using the number of competitors in the industry over time.

We next document the financial characteristics of interest that are related to predictions 1 and 2 in Section 3.4. They are defined as follows. R&D investment is measured by $(R\&D/TA)_{i,t}$, which is R&D expenditures scaled by total assets for firm i in year t. Assets-in-place are measured by $(PPE/TA)_{i,t}$, which is property, plant, and equipment scaled by total assets. Cash is represented by $(Cash/TA)_{i,t}$, which is measured by cash and short-term investments scaled by total assets. Debt is represented by $(Debt/TA)_{i,t}$, which is the sum of total long-term debt and short-term debt (debt in current liabilities). Net debt is represented by $(Net\,Debt/TA)_{i,t}$, where $Net\,Debt_{i,t} = Debt_{i,t} - Cash_{i,t}$. The mean values of these variables across all firms are calculated for each year in the sample.

In order to examine prediction 3 of the theoretical model, we construct time-series estimates of stock return volatility and betas for the biopharma industry. To examine stock return volatility, we compute both the total stock return volatility and the idiosyncratic stock return volatility of firms in the biopharma industry. The calculation of idiosyncratic stock return volatility requires a measure of the idiosyncratic component of total stock returns, which we calculate in the following way. First, the betas for the Fama and French (1993)

[11] Our results are also similar when using other sales-based measures of concentration, such as the 8-firm Concentration Ratio (where $M = 8$ in (1)), Herfindahl-Hirschman Index, or the Hannah and Kay (1971) Index. We include these measures in the Appendix.

three-factor model are calculated using a rolling two-year window of daily returns:

$$R_{i,t} - r_f = \alpha + \beta_{i,t,mkt}\left(R_{m,t} - r_f\right) + \beta_{i,t,SMB}R_{SMB,t} + \beta_{i,t,HML}R_{HML,t} + \epsilon_{i,t}. \tag{2}$$

Second, once the betas have been calculated for each day, the idiosyncratic portion of the return ($\epsilon_{i,t}$) is estimated using the beta estimates and (2).

We take two simple approaches to calculating the total and idiosyncratic volatility of the biopharma industry. The first approach, which is consistent with Officer (1973) and others, is to calculate volatility by taking the standard deviation of a rolling window of the past 360 days of daily returns. We calculate these rolling volatilities at the individual stock level and then average the volatilities at each date across all stocks, and we also consider the rolling return volatilities of a value-weighted portfolio of biopharma firms. This is done for both total stock returns and for idiosyncratic returns. We let $\sigma_{i,t}$ represent total stock return volatility for firm i, $\sigma_{P,t}$ represent portfolio return volatility, $\sigma_{i,t}^{idio}$ represent idiosyncratic return volatility for firm i, and $\sigma_{P,t}^{idio}$ represent idiosyncratic portfolio return volatility.

As noted by Schwert (1989) and French, Schwert, and Stambaugh (1987), a potential concern of the above procedure is autocorrelation in the return series, which may bias the volatility estimates. Therefore, our second approach to calculating volatility is to use non-overlapping samples of daily data to construct monthly volatility estimates. Specifically, we follow Bali, Cakici, Yan, and Zhang (2005) and calculate a measure of average stock variance. We first calculate the monthly variance of a stock i within a month T as the sum of the squared daily returns of that stock within the month. These monthly variance estimates are then averaged across all stocks, to create an average stock variance for month T:

$$\left(\hat{\sigma}_T\right)^2 = \frac{1}{N_T}\sum_{i=1}^{N_T}\left[\sum_{t=1}^{D_T} R_{i,t}^2\right], \tag{3}$$

where D_T is the number of days in month T, $R_{i,t}$ is the return of stock i on day t, and N_T

is the total number of stocks that exist in month T.[12] The average stock standard deviation (volatility) is given by the square root of the variance, i.e. $\hat{\sigma}_T = \sqrt{(\hat{\sigma}_T)^2}$. Similarly, average idiosyncratic return variance for month T is given by:

$$\left(\hat{\sigma}_T^{idio}\right)^2 = \frac{1}{N_T}\sum_{i=1}^{N_T}\left[\sum_{t=1}^{D_T}\epsilon_{i,t}^2\right], \tag{4}$$

and the average idiosyncratic volatility is given by $\hat{\sigma}_T^{idio} = \sqrt{\left(\hat{\sigma}_T^{idio}\right)^2}$. For robustness, we also calculate monthly volatilities as in Schwert (1989). We include these estimates in the Appendix.

Finally, to examine the time-series trend of betas for the biopharma industry, we form a value-weighted portfolio of biopharma firms, and calculate the Fama-French factor betas (given by (2) above) of the portfolio using a rolling 2-year window of daily portfolio returns.

3.2 Data and Summary Statistics

The focus of the empirical results is on the biopharma industry, which we take to be comprised of 4-digit Standard Industry Classification (SIC) codes 2830-2836.[13] The sample period is from 1950 to 2012. For our financial characteristic data, we include all biopharma firms that are listed in the Compustat database. The data encompass a total of 15,366 firm-year observations. For stock return data, we take all biopharma firms from the CRSP database for which daily data is available, which encompass 2,356,868 daily return observations.[14] Daily return data for the Fama-French factors and the risk-free rate of return were

[12] This calculation of stock variance differs slightly from Bali et. al. (2005) in that they include a term that includes the cross-product of adjacent returns within the month, as in French, Schwert and Stambaugh (1987). The calculation of the monthly variance in (3) follows from Schwert (1989), who notes that including cross-products of returns may lead to negative volatility estimates. One could also make an adjustment for the mean return in the calculation of the monthly variance, but Schwert (1989) notes that the differences in the estimates are very small.

[13] These are made up of Drugs (2830), Biological Products (2831), Medicinal Chemical and Botanical Products (2833), Pharmaceutical Preparations (2834), In Vitro and In Vivo Diagnostic Substances (2835), and Biological Products except diagnostics (2836). These are the same SIC codes that comprise the Fama and French (1993) "Drugs" industry.

[14] Daily data from 1948 and onwards is used to estimate betas and volatilities for the years 1950 and 1951.

obtained from Ken French's web site.[15] All variables except for those formed from stock returns are winsorized at the 1% level in order to reduce the impact of extreme outliers.

Summary statistics for all of the variables are given in *Table 1*. The entries in *Table 1* show that R&D spending is substantial for the industry, averaging roughly 32% of total assets over the sample period. In addition, cash holdings are also substantial, averaging 45% of total assets. While the mean level of debt is somewhat high at 26% of total assets, the much lower median and 25th percentile values (as well as high standard deviation) indicate that the distribution is skewed—there are firms with substantial amounts of debt on their balance sheet that drive the mean up. However, accounting for cash holdings and computing net debt, the mean firm in the industry as well as the median firm hold substantially negative net debt as a result of their cash holdings.

Table 1 also contains summary statistics for the volatility and beta estimates. The mean volatility of daily returns, calculated from rolling 360-day windows, is 3.1% for total volatility and 2.9% for idiosyncratic volatility. Consistent with portfolio diversification benefits, the numbers are lower when considering rolling volatilities of daily portfolio returns, 1% and 0.5% for total and idiosyncratic volatility, respectively. The monthly average volatility estimates are higher, at roughly 17% for total volatility and 14.1% for idiosyncratic volatility. Finally, for the beta estimates, the mean market beta for the industry is roughly 0.90, indicating that the biopharma industry co-moves less than one-for-one with the market. The mean of the SMB beta is slightly less than 0; however the standard deviation and 75th percentile indicate that it is also positive for a number of years. The mean of the HML beta is negative, and while the standard deviation indicates substantial variability, the negative percentile values also indicate that it is negative for most years.

[15] http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

Table 1: Summary Statistics

This table provides summary statistics for all variables. $CR_t(4)$ is the 4-firm concentration ratio for year t, defined by equation (1). $(R\&D/TA)_{i,t}$ is R&D expenditures scaled by total assets. $(PPE/TA)_{i,t}$ is property, plant, and equipment scaled by total assets. $(Cash/TA)_{i,t}$ is cash and short-term investments scaled by total assets. $(Debt/TA)_{i,t}$ is debt, which is the sum of total long-term debt and short-term debt (debt in current liabilities), scaled by total assets. $(Net\,Debt/TA)_{i,t}$ is net debt scaled by total assets, where $Net\,Debt_{i,t} = Debt_{i,t} - Cash_{i,t}$. $\sigma_{i,t}$ is individual stock return volatility, and $\sigma^{idio}_{i,t}$ is individual idiosyncratic return volatility, both calculated from a rolling window of the past 360 daily returns for each stock. $\sigma_{P,t}$ is value-weighted portfolio return volatility and $\sigma^{idio}_{P,t}$ is idiosyncratic value-weighted portfolio return volatility, calculated from the past 360 daily returns for the value-weighted portfolio of biopharma stocks. $\hat{\sigma}_T$ is the monthly estimate of average stock volatility, given by (3), and $\hat{\sigma}^{idio}_T$ is the monthly estimate of average idiosyncratic volatility given by (4). $\beta_{t,mkt}$, $\beta_{t,SMB}$, and $\beta_{t,HML}$ are the betas of the market, size, and value Fama-French factors, estimated using a rolling 2-year window of daily value-weighted portfolio returns. All variables run from 1950 to 2012. All financial characteristic variables are winsorized at the 1% level.

Variable	Mean	SD	p25	Median	p75
$CR_t(4)$	0.387	0.066	0.339	0.368	0.453
$(R\&D/TA)_{i,t}$	0.317	0.354	0.066	0.183	0.426
$(PPE/TA)_{i,t}$	0.173	0.165	0.039	0.125	0.267
$(Cash/TA)_{i,t}$	0.447	0.324	0.131	0.420	0.765
$(Debt/TA)_{i,t}$	0.258	0.465	0.0003	0.087	0.286
$(Net\,Debt/TA)_{i,t}$	−0.185	0.635	−0.679	−0.248	0.104
$\sigma_{i,t}$	0.031	0.015	0.018	0.027	0.043
$\sigma^{idio}_{i,t}$	0.029	0.014	0.016	0.025	0.039
$\sigma_{P,t}$	0.010	0.004	0.008	0.009	0.011
$\sigma^{idio}_{P,t}$	0.005	0.002	0.004	0.005	0.006
$\hat{\sigma}_T$	0.166	0.086	0.090	0.160	0.217
$\hat{\sigma}^{idio}_T$	0.141	0.077	0.076	0.127	0.186
$\beta_{t,mkt}$	0.904	0.173	0.779	0.892	1.060
$\beta_{t,SMB}$	−0.087	0.258	−0.247	−0.130	0.086
$\beta_{t,HML}$	−0.362	0.339	−0.578	−0.298	−0.144

3.3 Time-Series Evidence on Average Trends

Measures of Competition

The top two graphs of *Figure 2* show the value of of the Concentration Ratio for the biopharma industry over time. As can be seen from the graphs, the Concentration Ratio has shown a steady decline over time from 1950 until the mid 1990s, and then has exhibited a slight upward trend.[16] Similarly, the number of competitors in the industry has steady increased until the mid-1990s, after which it has remained relatively flat. Overall, both the Concentration Ratio and the number of competitors in the industry indicate that concentration in the biopharma industry has gone down (and thus that competition has gone up) substantially over time from 1950. This is consistent with existing papers (e.g. Caves, Whinston, and Hurwitz (1991), Grabowski and Vernon (1990, 1992), and others), who have shown that the industry has become more competitive over time.

Financial Characteristics

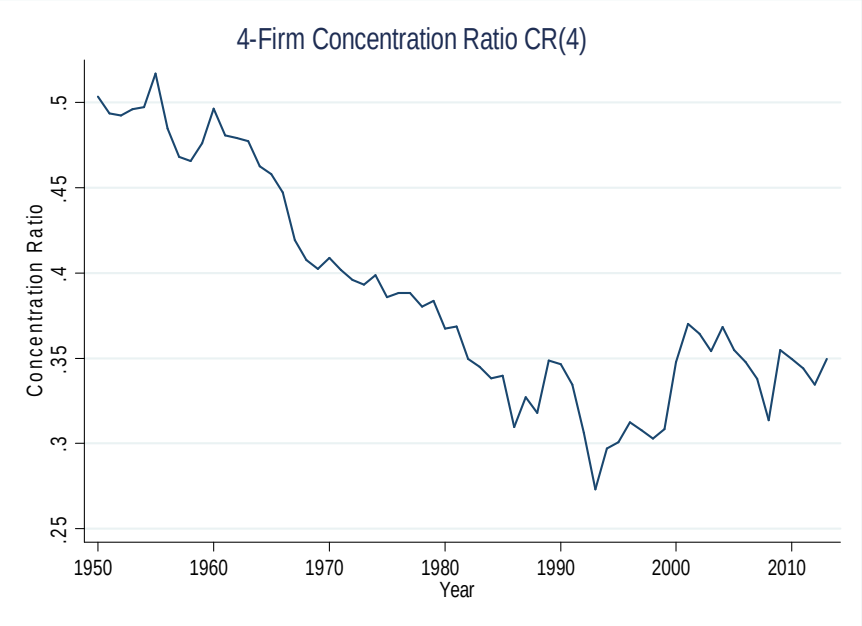
Taking this increase in competition over time as a given, we now examine the financial characteristics of firms in the biopharma industry. *Figure 3* shows how the financial characteristics of the biopharma industry have evolved over time. The mean and median values of $(R\&D/TA)_{i,t}$, $(PPE/TA)_{i,t}$, $(Cash/TA)_{i,t}$, $(Debt/TA)_{i,t}$, and $(Net\,Debt/TA)_{i,t}$ are calculated for each year. In order to distinguish these trends from larger trends that may also be taking place in other industries, the mean values of these variables are also included for all other industries apart from the biopharma industry.

The graphs presented in *Figure 3* are consistent with predictions 1 and 2 of the theoretical model. In particular, as competition has increased over this time period, both mean and median R&D expenditures have increased, while assets-in-place (measured by PPE) have

[16] For robustness, in *Figure B1* of the Appendix, we also present the same trends for alternative sales-based competition ratios: the 8-firm Concentration Ratio (where $M = 8$ in (1)), the Herfindahl-Hirschman Index, and the Hannah and Kay (1971) Index. The results are qualitatively similar.

Figure 2: Competition in the Biopharma Industry

These figures present estimates of competition over time for the biopharma industry. The top figure gives the 4-firm Concentration Ratio. The ratio is calculated for each year using equation (1), and a higher number indicates increased concentration. The bottom figure gives the number of competitors in the biopharma industry over time.



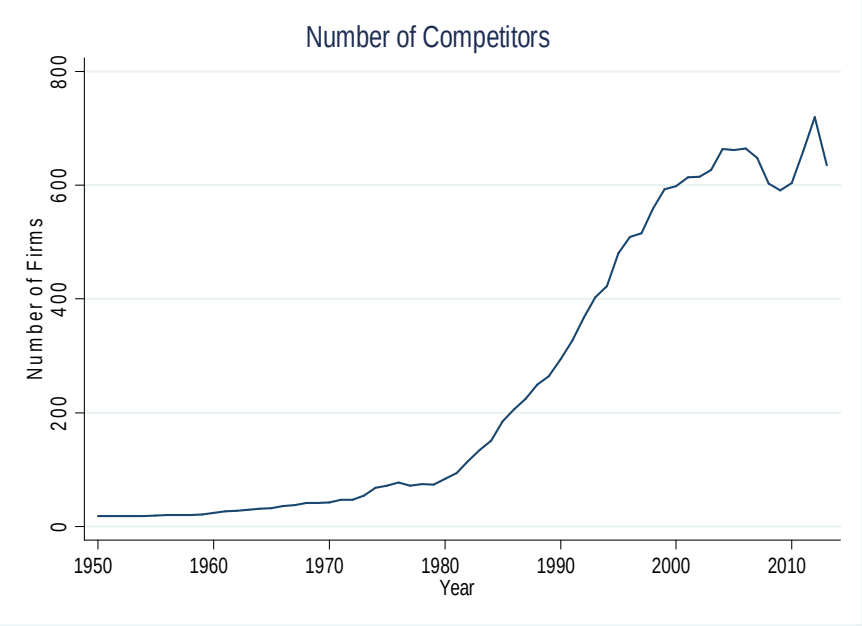


Figure 3: Financial Characteristics over Time

These graphs show the mean (solid blue line) and median (dashed red line) values of financial characteristics for the biopharma industry in each year. The green dotted lines represent the mean values of financial characteristics for all other industries.

decreased sharply.[17] Moreover, cash holdings have increased substantially over this time period. Finally, while the mean level of debt has increased over time (mostly in the 1970s and the 2000s), the median level of debt has declined consistently from the mid-1970s. As the summary statistics also indicated, the debt levels are cross-sectionally skewed across firms, with some firms holding very large amounts of debt—this drives the mean values upwards. But the median debt levels indicate that the majority of firms have decreased their debt levels in the industry. Net debt shows a similar trend, although the decline in both mean and median values are more marked until the late-1990s. While the mean level increases after that point (concurrent with the increase in debt), the median level of net debt stays relatively flat, consistent with how the competition measures behaved over this period. For all of the variables, the trends for the biopharma industry are more striking than those for other industries, suggesting that the trends we observe for the biopharma industry are not driven by aggregate trends affecting all industries.[18]

Stock Return Volatility

For the volatility time-series trends of the biopharma industry, we begin by examining the rolling total and idiosyncratic stock return volatility of individual stocks in the biopharma industry, averaged at each date—i.e. the mean levels of $\sigma_{i,t}$ and $\sigma_{i,t}^{idio}$ at each date. The results are shown in panel (a) of *Figure 4*. The evidence is consistent with the predictions of the model. Specifically, total stock return volatility and idiosyncratic volatility have both increased substantially over time, as competition has also increased. This effect is the most striking for the post-1960s time period, when the number of firms increases substantially.

[17]The secular increase in mean R&D expenditures understates an interesting cyclicality. One explanation for this cyclicality is a change in profitability each year, which partly determines how much firms are able to spend on R&D—and which in turn is partly dependent on the overall state of the economy. A graph of R&D expenditures scaled by earnings reveals a smoother trend over time.

[18]The trends for R&D, cash, and assets-in-place remain relatively flat until the mid-1970s, while debt increases during this early time period. While this is in contrast to the reduction in the Concentration Ratio during this time period, this is consistent with the number of competitors (as shown in *Figure 2*) also being relatively flat during this period. As previously discussed, sales-based measures of competition may not be ideal for this industry, and thus these measures may not accurately gauge competition during certain periods.

Panel (b) of *Figure 4* depicts the rolling total and idiosyncratic stock return volatility of a value-weighted portfolio of biopharma firms over time (represented by $\sigma_{P,t}$ and $\sigma_{P,t}^{idio}$). The dotted red lines represent trend lines. In general, the level of volatility is lower for the portfolio, as a result of diversification. While not as striking as the results in panel (a) of *Figure 4*, both total and idiosyncratic volatility have trended upwards (as shown by the dotted red trend lines). Total stock return volatility exhibits a number of periods of large spikes in volatility, especially after the mid-1980s. The same is true for idiosyncratic stock return volatility after the 1970s, which in addition also has a very large spike around 2001, which may be attributable to the September 11th attacks and also the bursting of the private equity bubble. While there is a substantial decline in volatility in the years following that, both graphs generally show an increased number of periods of high volatility over time.

The evidence in both panels of *Figure 4* is consistent with the predictions of the model. Specifically, total stock return volatility and idiosyncratic volatility have both increased substantially over time, as competition has also increased. This effect is the most striking for the post-1960s time period, when the number of firms increases substantially. These results are also consistent with the findings of Irvine and Pontiff (2009), who argue that an increase in idiosyncratic volatility of the average stock is attributable to more intense economy-wide competition.

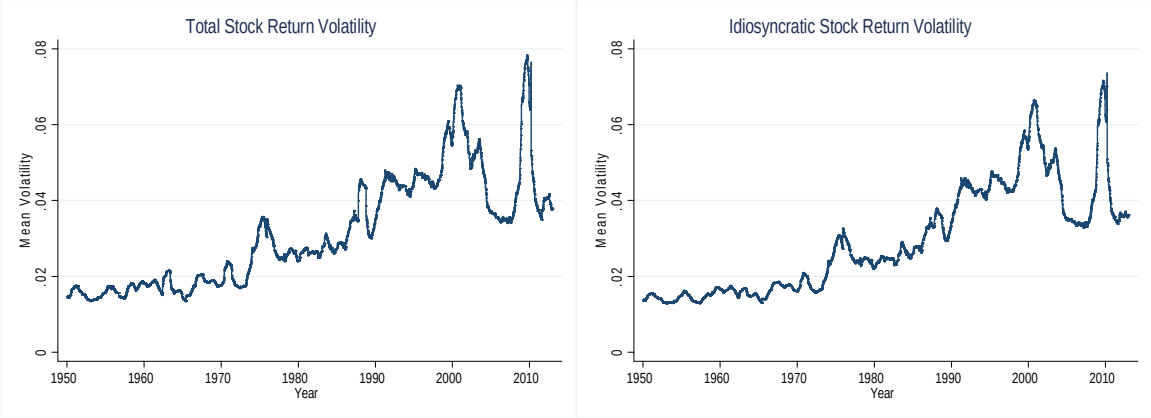
We next examine the volatility of the biopharma industry using non-overlapping monthly volatilities. *Figure 5* depicts average monthly stock volatility as in Bali et al. (2005), as described in equations (3)–(4). In panel (a) of *Figure 5*, the left graph shows total stock volatility (described by equation (3)), while the right graphs shows idiosyncratic stock volatility (described by equation (4)). Panel (b) of *Figure 5* illustrates a simple 12-month moving average of the graphs in Panel (a). Overall, the graphs illustrate a clear trend of increasing volatility over time, consistent with the predictions of the model as competition has increased.[19] For further robustness, *Figure B2* in the Appendix gives additional monthly

[19] A possible concern is that the upward trend in volatility is stochastic rather than deterministic in nature. To examine this, we also run Augmented Dickey-Fuller tests on the monthly series to test for the presence

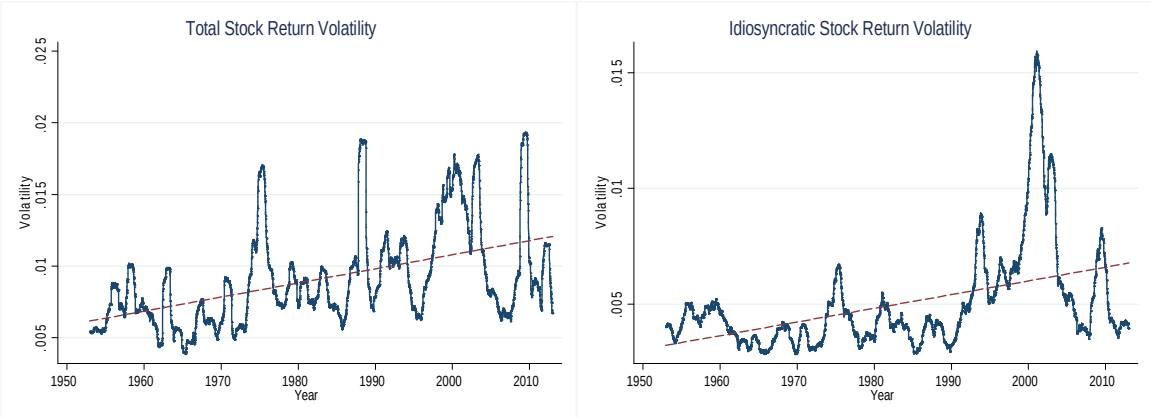
Figure 4: Total and Idiosyncratic Stock Return Volatility

Panel (a) shows total and idiosyncratic volatility for the biopharma industry, calculated as the average, at each date, of total and idiosyncratic stock return volatility of individual stocks. The left figure of panel (a) shows total stock return volatility for the biopharma industry, while the right figure of panel (a) shows mean idiosyncratic stock return volatility for the biopharma industry. Total stock return volatility is calculated using the rolling standard deviation of the past 360 days of daily returns and then averaged across all firms each day, while idiosyncratic volatility is calculated using the rolling standard deviation of the past 360 days of individual daily idiosyncratic returns from (2) and then averaged across all firms each day. Panel (b) shows total (left figure) and idiosyncratic (right figure) volatility for a value-weighted portfolio of firms in the biopharma industry. Total stock return volatility is calculated using the rolling standard deviation of the past 360 days of daily value-weighted portfolio returns, while idiosyncratic volatility is calculated using the rolling standard deviation of the past 360 days of daily idiosyncratic portfolio returns from (2).

(a) Mean Levels of $\sigma_{i,t}$ and $\sigma_{i,t}^{idio}$



(b) Levels of $\sigma_{P,t}$ and $\sigma_{P,t}^{idio}$



estimates of value-weighted portfolio volatility.

Betas

The betas of a value-weighted portfolio of biopharma firms are shown in *Figure 6*. The dotted lines represent trend lines for the different beta estimates. As can be seen in the figure, the beta estimates for all three factors have generally declined from 1950 and onward. The market beta exhibits a somewhat gradual decline over the time period, from slightly over 1.0 in 1950 to roughly 0.7 in 2012. However, the decline over time is more striking for the SMB and HML factor betas. The SMB factor beta shows a clear downward trend from 1950 until 2000, though it has trended upward since 2000. The HML factor beta also exhibits a striking downward trend from 1950 through the mid-to-late 1990s. While this trend does not continue after the late 1990s, this coincides with the slight increase in concentration in the industry around the same time, as depicted in *Figure 2*. In addition, the two large spikes during this period may be attributable to the bursting of the dot com bubble in the late 1990s and the September 11th terrorist attacks in 2001/bursting of the private equity bubble. The beta estimates may be affected by the changes in debt and cash levels over time; hence, we re-ran our analysis using *unlevered* stock returns—constructed using a simple unlevering formula—and our results and main findings are unchanged.[20] Overall, the declines in beta over time are consistent with the predictions of the model that firms will substitute investments in assets-in-place (which carry systematic risk) for investments in R&D (which carry idiosyncratic risk).

Table B1 of the Appendix summarizes the direction and significance of the relationship between the various financial characteristics and measures of competition through time-series regressions.

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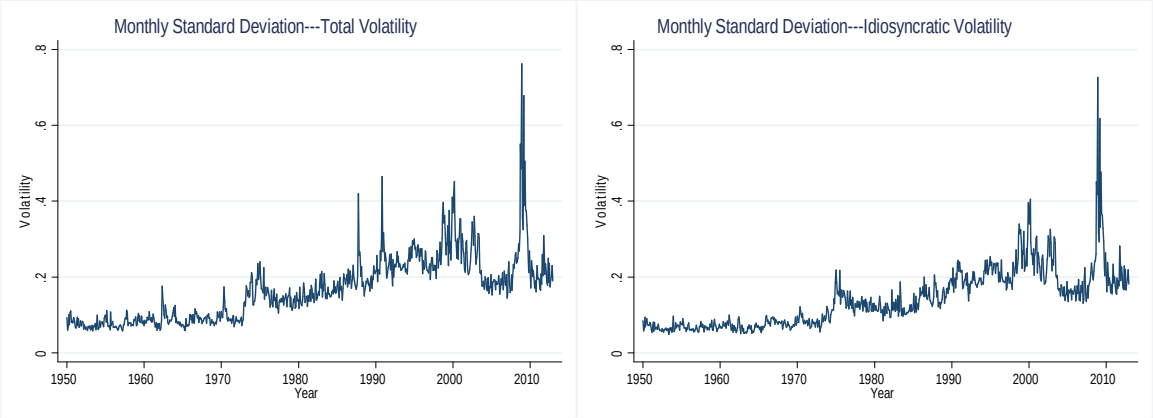
of a unit root. For both total volatility and idiosyncratic volatility, Augmented Dickey-Fuller tests reject the presence of a unit root at at least the 5% level when up to 5 lags are included, regardless of whether a trend is included.

[20] Results available upon request.

Figure 5: Total and Idiosyncratic Stock Return Volatility

Monthly estimates of total return volatility and idiosyncratic volatility. Panel (a) depicts of monthly estimates of average (across all firms in a given month) total and idiosyncratic stock volatility, as in Bali et. al. (2005). The left graph of panel (a) is total stock volatility, as described by equation (3). The right graph of panel (a) is idiosyncratic stock volatility, as described by equation (4). Panel (b) gives 12-month simple moving averages of the graphs in panel (a).

(a) Levels of $\hat{\sigma}_T$ and $\hat{\sigma}_T^{idio}$



(b) Moving Average of $\hat{\sigma}_T$ and $\hat{\sigma}_T^{idio}$

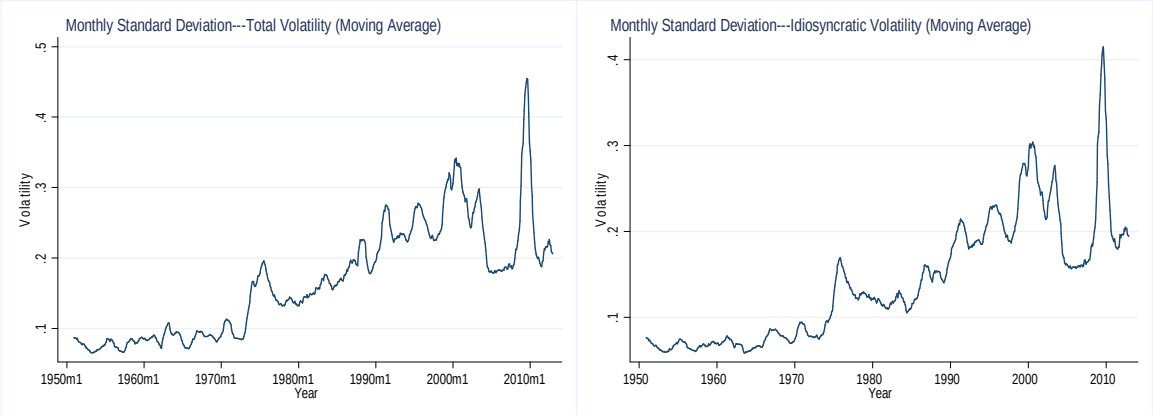
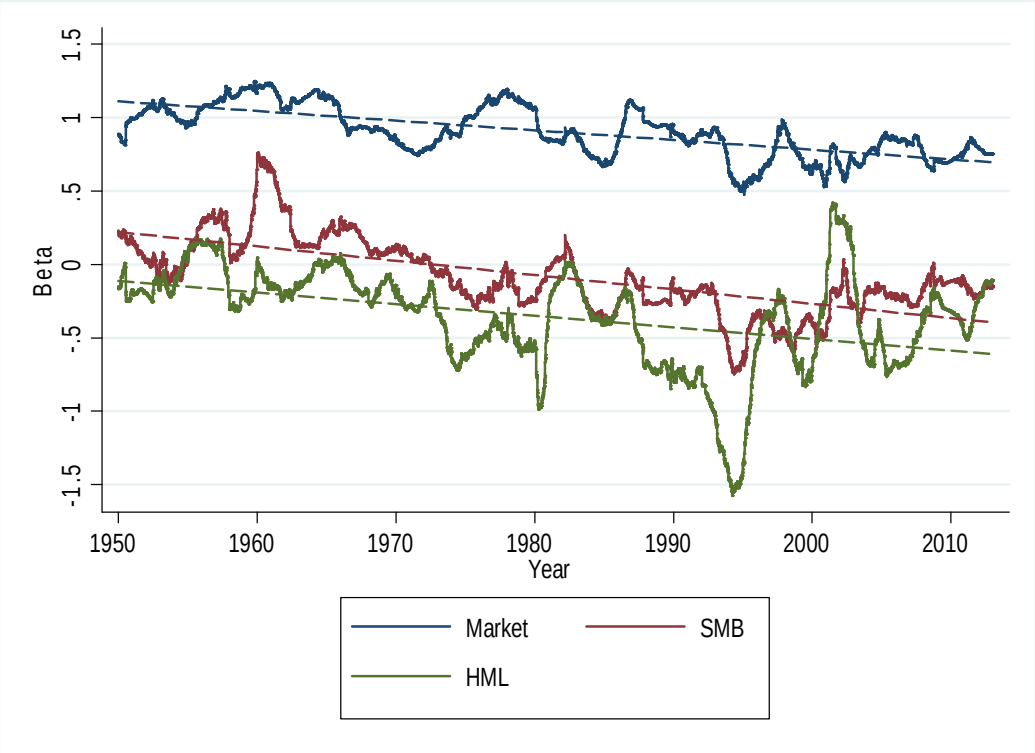


Figure 6: Biopharma Industry Value-weighted Betas

This figure shows the betas of a value-weighted portfolio of biopharma stocks, calculated via the Fama-French 3-factor model using a rolling 2-year window of daily stock returns. The blue line represents the market factor, the green line represents the market-to-book factor (HML), and the red line represents the size factor (SMB). The dotted lines are trend lines for the factors.



4 Differences-in-Differences Analysis

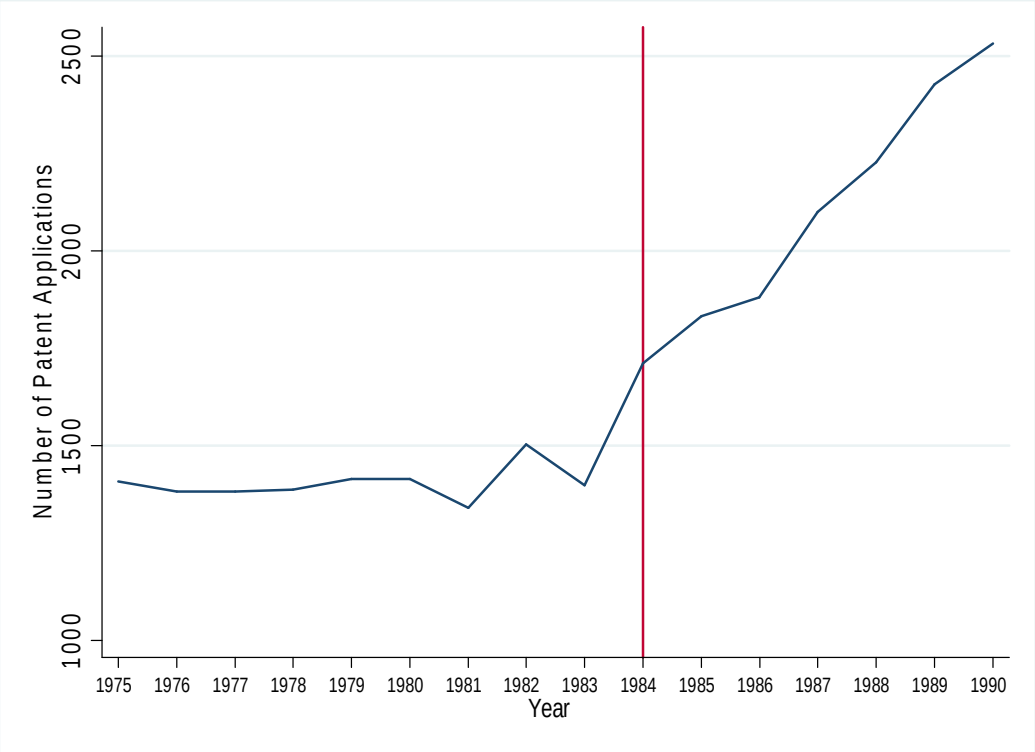
While the previous empirical evidence is consistent with the predictions of the model, a limitation of the evidence is that it treats the increase in competition as exogenous over time. However, this assumption may be violated in practice. For example, R&D outlays by incumbent firms can act as a competitive entry barrier, thus creating an endogeneity problem—R&D is affected by competition, but competition is also affected by R&D. In order to overcome this, we exploit the exogenous variation in competition introduced by the passage of the Drug Price Competition and Patent Term Restoration Act of 1984.

The Drug Price Competition and Patent Term Restoration Act of 1984 (informally known as the Hatch-Waxman Act, and henceforth referred to as such) was introduced for the expressed purpose of increasing competition in the drug marketplace, by facilitating the entry of generic drugs after the expiration of a patent. Prior to the passage of the Hatch-Waxman Act, onerous Food and Drug Administration requirements made it necessary for generic drugs to replicate many of the original drug's tests in order to gain market approval. However, once the law was passed, generic drugs only needed to prove bioequivalence to the original drug, thus greatly decreasing the barriers to competitive entry. A number of papers have provided evidence that the Hatch-Waxman Act did indeed increase competition and facilitate the entry of generic drugs. See, for example, analysis and evidence by Grabowski and Vernon (1986, 1992), who look at entry, market share, and price data for a sample of drugs after the enactment of the law, as well as Grabowski (2007) for an overview.

Evidence of the effect of the law on competition in the biopharma industry can also be seen empirically through the competition measures. As shown in *Figure 2*, the number of new entrants increases substantially after 1984, although there is an increasing trend in the years prior. The Concentration Ratio experiences a signficant drop around 1990. While this drop occurs a number of years after the passage of the Hatch-Waxman Act, this delay is consistent with the Concentration Ratio being a sales-based competition measure. Since all drugs must first pass the FDA approval process before they can be sold, which takes a

Figure 7: Biopharma Patent Applications

This figure depicts the number of new whole patent applications from 1975 to 1990 by U.S. firms in the pharmaceutical and medicines industry. Data is taken from the U.S. Patent and Trademark Office.



number of years, new entrants will not be expected to affect the sales of the industry until several years after their entry. We therefore present an additional indicator of competition in the industry—the number of patent applications filed by biopharma firms. As patent applications can be filed even in the early stage of a drug's development, the number of patents filed can be viewed as an indicator of the intensity of R&D competition. *Figure 7* graphs the number of whole patent applications filed by U.S. biopharma firms around the introduction of the Hatch-Waxman Act.[21] As can be seen from the figure, the number of new patent applications is flat before 1984, but starting in 1984 the number of applications began to sharply increase. This is consistent with the Hatch-Waxman Act facilitating greater competition amongst biopharma firms.

[21]Data is taken from the U.S. Patent and Trademark Office (USPTO).

4.1 Empirical Methodology

The ideal test is to find two groups of firms with similar characteristics (as defined by the theory), exogenously change the degree of competition for one group, and then see if the resulting difference conforms to the predictions of the theory. We use the Hatch-Waxman Act as a source of exogenous variation in order to conduct a differences-in-differences analysis to provide cleaner empirical support for the predictions of the theory. As the Hatch-Waxman Act specifically influenced the biopharma industry through an increase in competition, the treatment group consists of biopharma firms (SIC codes 2830-2836). Since the theory is applicable for firms in R&D-intensive industries, we choose firms from the five top R&D-intensive industries other than biopharma as our control group.[22] A concern is that the control group has different characteristics and is thus not properly comparable to the biopharma industry. To account for this, we therefore use propensity-score matching to choose firms from the other R&D-intensive industries that are comparable to the firms in our biopharma sample based on observable characteristics in the period before the law was passed.[23] The pre-period is from 1975 to 1983, while the post-period is from 1984 to 1995. The resulting sample consists of 959 firms, for a total of 4,596 firm-years of data for the control group, and a total of 4,374 firm-years of data for the treatment group.

A critical assumption of the differences-in-differences framework is that the treatment and control groups exhibit parallel trends in terms of the outcome variables prior to the event in question. For the financial characteristic variables, *Figure 8* provides graphical

[22]These industries are identified by the NSF (National Science Foundation (1999)) as being the top R&D-intensive industries, and include: Industrial and other chemicals (2-digit SIC code 28, excluding 3-digit code 283), industrial and commercial machinery and computers (2-digit SIC code 35), electrical equipment (2-digit SIC code 36), transportation equipment including aircraft and missiles (2-digit SIC code 37), and measuring and analyzing equipment (2-digit SIC code 38).

[23]More specifically, we choose firms in the other R&D-intensive industries that match biopharma firms based on observable characteristics in the years between 1975 and 1984. The matching characteristics are: size ($\log(TA)$), profitability ($EBIT/TA$), capital structure ($Net\ Debt/TA$), dividend payout, and investment opportunities as proxied by market-to-book (ME/BE). We allow matches between multiple firms (i.e. we implement matching with replacement, allowing up to three matches), although this assumption does not have a material impact on our results. We further restrict our choice of control firms to the ones which are on a common support in terms of these observable characteristics before the implementation of the law. Our results are also robust to a one-to-one matched biopharma and control group sample over the sample period.

evidence for the years surrounding the passage of the Hatch-Waxman Act, that examines this assumption for the control group. In these graphs, the solid blue lines represent average values for the biopharma industry, while the dashed red lines represent average values for other R&D-intensive firms. The vertical red lines represent the year that the Hatch-Waxman Act was implemented. The levels of R&D expenditures, cash holdings, debt, net debt, and assets-in-place are all similar for both biopharma and the control group in the pre-period, showing that these two industries are similar in terms of these financial characteristics. Moreover, these characteristics exhibit strong parallel trends before the Hatch-Waxman Act was implemented. After the Act was implemented, the values for the two groups diverge in a way consistent with the predictions of the model. Specifically, in the period following the enactment of the law, R&D expenditures and cash holdings for biopharma firms appear to increase sharply relative to the control group, while debt, net debt, and assets-in-place appear to decrease relative to the trend for the control group. Overall, the graphs provide evidence supporting the appropriateness of the differences-in-differences analysis in this setting, and also provide suggestive evidence for the effect of the Hatch-Waxman Act on the financial characteristics of the biopharma industry.[24]

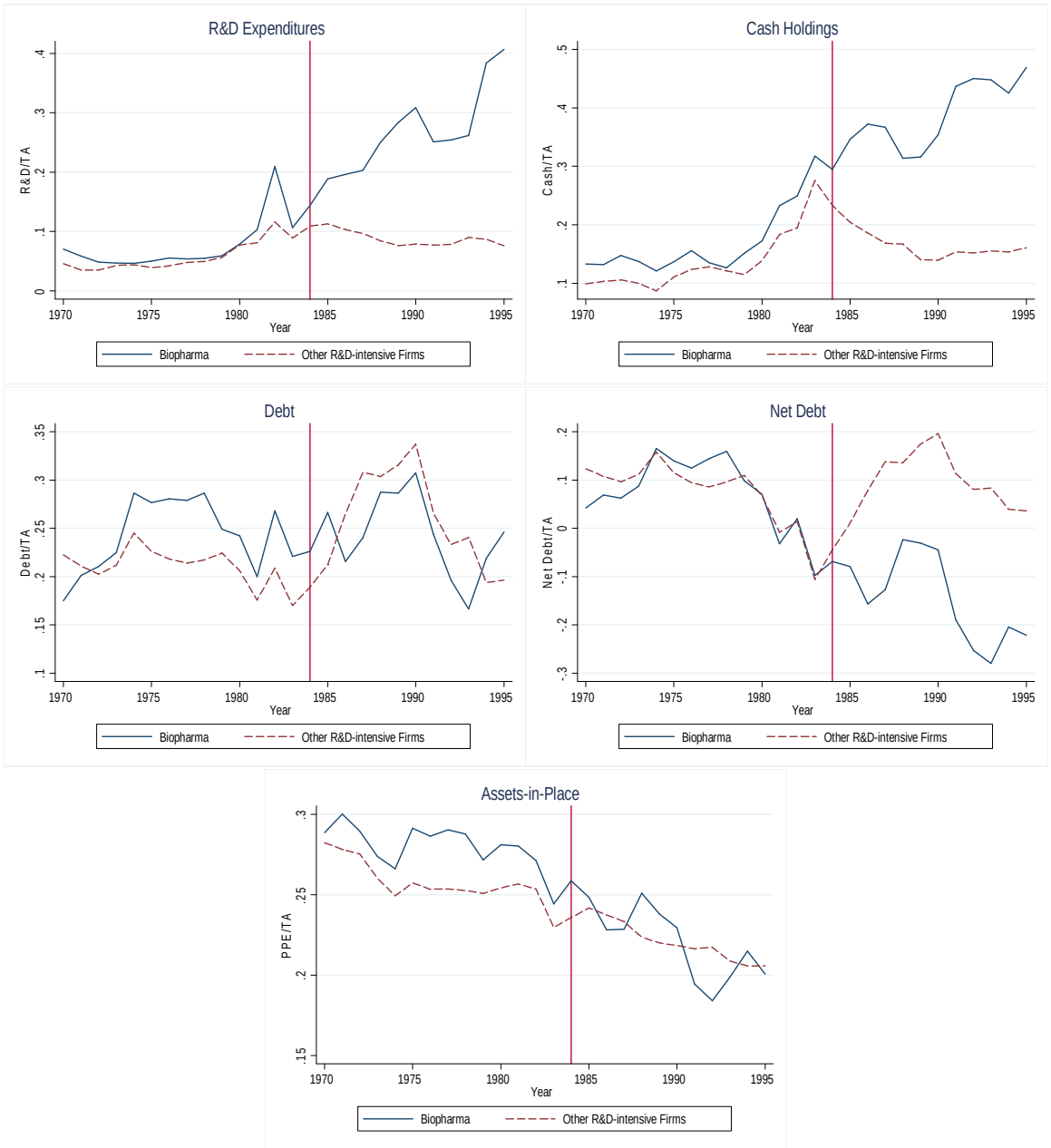
For a more formal analysis, we estimate the following regression for the financial characteristic predictions:

$$Y_{i,t} = \gamma_0 + \gamma_1 HW_t + \gamma_2 Biopharma_i + \gamma_3 HW_t \times Biopharma_i + \eta X_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \quad (5)$$

In (5), $Y_{i,t}$ represents the dependent variable of interest for firm i in year t, predicted to vary

[24]A further assumption of the differences-in-differences framework in this setting is that the event (i.e. the Hatch-Waxman Act) increased competition for the biopharma industry relative to the control group. While the Hatch-Waxman Act dealt with drug development and thus was targeted specifically toward the biopharma industry, we explicitly test this assumption in order to rule out any sharp changes in competition that may have affected the control group at the same time. *Figure B3* of the Appendix examines changes in competition as measured by the Concentration Ratio (CR(4), both graphically and through a differences-in-differences regression. While the Concentration Ratio and other sales-based measures of concentration are likely imperfect measures of competition for the biopharma industry, as we previously argued, the results show that the Concentration Ratio dropped for the biopharma industry relative to the control group after the Hatch-Waxman Act, which is consistent with it increasing competition for the biopharma sector.

Figure 8: Financial Characteristic Trends for Treatment and Control Group
Trends for financial characteristic variables for R&D expenditures, cash holdings, debt, net debt, and assets-in-place, all scaled by total assets. All variables are averages for each group. The solid blue lines give averages for the biopharma industry, while the red dashed lines give averages for the propensity-score-matched sample of R&D-intensive firms. A vertical red line is included in each graph, representing the year that the Hatch-Waxman Act was implemented.



as a function of competition by the theoretical model. HW_t is an indicator variable which takes a value of 1 if the year is 1984 or later, which is the period after the Act was enacted into law. $Biopharma_i$ is an indicator variable which takes a value of 1 if firm i is in the biopharma industry. It follows that the that the regression estimate of γ_3 is the differences-in-differences estimator—the effect of the increase in competition stemming from the Hatch-Waxman Act on $Y_{i,t}$. For the financial characteristics, the dependent variable $Y_{i,t}$ represents the variable of interest for firm i in year t, as predicted by the theoretical model. Specifically, for the financial characteristics, we examine $(R\&D/TA)_{i,t}$, $(PPE/TA)_{i,t}$, $(Cash/TA)_{i,t}$, $(Debt/TA)_{i,t}$, and $(Net\,Debt/TA)_{i,t}$ as choices for $Y_{i,t}$. In order to control for the possibility of differential trends between the control and treatment groups, $X_{i,t}$ is a vector of control variables that may also covary with the dependent variable.[25] Finally, μ_i represents firm fixed effects, to control for time-invariant firm characteristics, and λ_t represents year fixed effects, to control for time-trends. Equation (5) is estimated for the period from 1975 to 1995.[26]

We also examine the effect of the Hatch-Waxman Act on the stock return risk variables. Specifically, we estimate a differences-in-differences regression for the period surrounding the implementation of the Act (from 1975 to 1995), in order to examine how the volatility and betas of biopharma and control R&D-intensive firms changed after the Act was put into law. Consistent with the approach in Section 3.1, the volatility and beta variables which we use as dependent variables are calculated for value-weighted portfolios of biopharma firms and control R&D-intensive firms. For the volatility variables, we calculate yearly values of total and idiosyncratic volatility ($\sigma_{P,t}$ and $\sigma^{idio}_{P,t}$) for value-weighted portfolios of both groups of firms using the standard deviation of each portfolio's daily total or idiosyncratic returns over the year. For the beta variables, we calculate yearly beta estimates of value-weighted

[25] Control variables included in $X_{i,t}$ for the financial characteristic variables include: $\log(NA_{i,t})$ (where $NA = TA - Cash$), $(PPE/TA)_{i,t}$, $(Cash/TA)_{i,t}$, $(EBIT/TA)_{i,t}$ (earnings as a fraction of total assets to control for profitability), $(ME/BE)_{i,t}$ (market value of equity to book value of equity), and $(Div/TA)_{i,t}$ (the amount of common/ordinary dividends paid). Cash and PPE are excluded as control variables in the cases when they are the dependent variables of interest.

[26] We choose this estimation window in order to capture any delayed effects of competition on the variables of interest, given the long gestation periods of biopharma projects. However, our results still hold for a shorter estimation window.

portfolios of biopharma and control firms via equation (2), using the past 720 days of daily returns.[27]

4.2 Results and Discussion

We begin by examining the effect of the increase in competition caused by the Hatch-Waxman Act on the financial characteristic variables predicted by the theory, and then examine the impact of Hatch-Waxman on the risk variables for the biopharma industry.

Effect on Financial Characteristics

The estimation results for regression (5) are included in *Table 2*. Results both with and without control variables and fixed effects are included.

Overall, the results from the differences-in-differences analysis are consistent with the predictions of the model. The differences-in-differences estimator for $R\&D$ is positive and significant with or without control variables and fixed effects (columns (1) and (2)). This indicates that, as the Hatch-Waxman Act increased competition for the biopharma industry, firms in the industry increased their R&D relative to the control group. The differences-in-differences estimator for PPE is negative and significant in column (3), which is consistent with the prediction of the model, but is insignificant in column (4) when including controls and fixed effects. Thus, the evidence for assets-in-place in this setting is mixed. The differences-in-differences estimator for $Cash$ is positive and significant whether controls are included or not, indicating that firms in the biopharma industry increased their cash holdings as a result of the Hatch-Waxman Act. The differences-in-differences estimator for *Debt* is negative and significant in column (7), and is also negative though insignificant in column

[27] *Figure B4* of the Appendix graphs trends for the risk variables and the control group surrounding the passage of the law. For the volatility estimates, both total and idiosyncratic volatility are at roughly the same level and exhibit strong parallel trends prior to the passage of the law, but then increase more for the biopharma industry than for the control group after the passage of the law. All three beta estimates drop by more for the biopharma industry than the control group following passage of the law. However, while the HML beta shows roughly parallel trends prior to the passage of the law, the parallel trend assumption may not hold well for the market beta and SMB betas.

Table 2: The Effect of the Hatch-Waxman Act on Financial Characteristics

This table estimates the differences-in-differences regression (5) for financial characteristics. The sample consists of biopharma firms and a control group consisting of propensity-score matched R&D-intensive firms, matched on size, profitability, capital structure, and market-to-book. The sample period spans from 1975 to 1995. The dependent variables consist of $R\&D$, PPE, $Cash$, $Debt$, and $Net\,Debt$, each scaled by total assets. HW_t is a dummy variable which takes a value of 1 if the year is 1984 or later, and a value of zero otherwise. $Biopharma_i$ is a dummy variable which takes a value of 1 if firm i is in the biopharma industry, and a value of 0 otherwise. Control variables include $\log(NA_{i,t})$, $(PPE/TA)_{i,t}$, $(Cash/TA)_{i,t}$, $(EBIT/TA)_{i,t}$, $(M/B)_{i,t}$, and $(Div/TA)_{i,t}$. Controls for cash and PPE are excluded when they are the dependent variable of interest. Year and firm fixed effects are included where indicated. Robust standard errors are given in parentheses, and standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	Dependent Variable:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	$R\&D$	$R\&D$	PPE	PPE	$Cash$	$Cash$	$Debt$	$Debt$	$Net\,Debt$	$Net\,Debt$
$HW_t \times Biopharma_i$	0.168***	0.023**	−0.033**	0.009	0.191***	0.030*	−0.066**	−0.014	−0.256***	−0.056*
	(0.017)	(0.010)	(0.014)	(0.012)	(0.021)	(0.017)	(0.028)	(0.020)	(0.039)	(0.030)
$Biopharma_i$	0.024**		0.025		0.037*		0.048**		0.012**	
	(0.012)		(0.015)		(0.019)		(0.020)		(0.031)	
HW_t	0.020***		−0.026***		0.008***		0.051***		0.042**	
	(0.006)		(0.007)		(0.009)		(0.018)		(0.022)	
Constant	0.071***	0.111***	0.250***	0.270***	0.164***	0.601***	0.204***	0.343***	0.040***	−0.422***
	(0.006)	(0.017)	(0.008)	(0.017)	(0.007)	(0.019)	(0.009)	(0.047)	(0.015)	(0.040)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Firm Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	7,502	6,448	8,479	7,223	8,487	7,223	8,465	7,223	8,465	7,223
Number of Firms	871	783	938	848	939	848	939	848	939	848
Adjusted R^2	0.117	0.820	0.015	0.783	0.164	0.831	0.002	0.575	0.044	0.696

(8), providing some evidence that firms in the biopharma industry decreased their debt as a result of the increase in competition. However, the estimator for $Net\,Debt$ is negative and significant in both columns (9) and (10), indicating that net debt also fell as a result of the increase in competition for the biopharma industry.

Effect on Risk Variables

The estimated impact of the Hatch-Waxman Act on the risk variables for the biopharma industry are given in *Table 3*. For both total and idiosyncratic stock return volatility, the differences-in-differences estimator is positive and significant, indicating that both total and idiosyncratic return volatility increased significantly more for the biopharma industry than for the control group immediately following the passage of the Hatch-Waxman Act, which is consistent with the predictions of the theory.

For the betas, the coefficient for $HW_t \times Biopharma_i$ is negative though insignificant for the beta of the SMB factor, but is negative and significant for the betas of the market and value (HML) factors. This decline in betas compared to the control group immediately following the Hatch-Waxman Act is consistent with the predictions of the theory. However, the results for the betas should be interpreted with some caution, as the parallel trends assumption may not hold well for the market and SMB betas.

Overall the empirical results for the risk variables support the predictions of the theory and suggest that the increase in competition brought by the Hatch-Waxman Act led to increased volatility but reduced betas for biopharma firms.

4.3 Robustness: A Falsification Test

As a robustness check to account for the possibility that our results are being driven by trends that started before our sample period, we conduct a falsification test for the financial characteristic variables, where we run regression (5) for the sample period from 1960 to 1980, but falsely specify that the Act was implemented in 1969. As before, biopharma firms

Table 3: The Effect of Competition on Risk Variables

This table estimates the change in the stock return risk variables for biopharma firms versus control group firms as a result of the Hatch-Waxman Act. The control group is a propensity-score matched sample of R&D-intensive firms, matched on size, profitability, capital structure, and market-to-book. The sample spans from 1975 to 1995. The dependent variables in columns (1) and (2) consist of the total and idiosyncratic stock return volatilities of value-weighted portfolios of biopharma or control firms (σ_t and σ_t^{idio}), calculated at the end of each year using daily returns. The dependent variables in columns (3)–(5) consist of the betas of value-weighted portfolios of biopharma or control firms, calculated as of the end of year t—the market beta $\beta_{mkt,t}$, size beta $\beta_{SMB,t}$, and value beta $\beta_{HML,t}$. HW_t is a dummy variable which takes a value of 1 if the year is after 1984, and a value of zero otherwise. $Biopharma_i$ is a dummy variable which takes a value of 1 if sector i is the biopharma industry, and 0 otherwise. Robust standard errors are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	Dependent Variable:				
	(1)	(2)	(3)	(4)	(5)
	σ	σ^{idio}	β_{mkt}	β_{SMB}	β_{HML}
$HW_t \times Biopharma_i$	0.004***	0.006***	−0.194**	−0.092	−0.298*
	(0.001)	(0.001)	(0.088)	(0.067)	(0.169)
$Biopharma_i$	0.001	−0.001*	−0.019	−0.144***	−0.328***
	(0.001)	(0.001)	(0.070)	(0.045)	(0.042)
Constant	0.033***	0.032***	1.007***	−0.075***	−0.158**
	(0.000)	(0.001)	(0.030)	(0.024)	(0.067)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	42	42	42	42	42
Adjusted R^2	0.926	0.905	0.245	0.579	0.432

are our treatment group, and we choose propensity-score matched (based on observable characteristics in the period from 1960 to 1969) R&D-intensive firms as our control group. As indicated in *Figure 2*, there are not as many biopharma firms operating during this period; as a result, the sample consists of a total of 181 firms with 2,461 firm-years of data.

The results of the falsification test are included in *Table 4*. R&D, assets-in-place, and cash are all insignificant whether or not controls and fixed effect are included. Although debt and net debt are significant (albeit with the opposite sign as predicted by the theory), they are both insignificant when fixed effects and controls are included. Overall, these results suggest that the results from the previous section are not caused by any long-term trends between the treatment and control groups, as the same results are not found in a different sample period.

5 Conclusion

In this paper, we explore the interaction between competition, R&D investments, and financing choices, as well as the implications of this interaction for the firm's risk profile. We motivate our empirical hypotheses with a simple model which predicts that, as competition increases, firms will increase R&D investment, reduce investment in assets-in-place, carry more cash, and have a lower level of net debt. Moreover, firm betas will decline, but idiosyncratic risk and total stock return volatility will rise. We provide time-series evidence about firms in the biopharma industry that is consistent with these predictions. However, since our predictions rely on an exogenous change in competition, whereas in reality competition has both exogenous as well as endogenous elements, we have used the Hatch-Waxman Act of 1984 as an exogenous variation that increased competition in the biopharma industry, and conducted a differences-in-differences test that produces evidence that strongly supports the model. This approach allows us to overcome the endogeneity concern about competition. Although we have focused on on the biopharma industry, our results are also applicable to

Table 4: **Falsification Test for the Differences-in-Differences Analysis**

This table estimates the differences-in-differences regression (5) for financial characteristics, but over the sample period from 1960 to 1980. The sample consists of biopharma firms and a control group consisting of propensity-score matched R&D-intensive firms, matched on size, profitability, capital structure, and market-to-book. The dependent variables consist of $R\&D$, PPE, $Cash$, $Debt$, and $Net\,Debt$, each scaled by total assets. Act_t is a dummy variable which falsely specifies the passage of the Hatch-Waxman Act—it takes a value of 1 if the year is 1969 or later, and a value of zero otherwise. $Biopharma_i$ is a dummy variable which takes a value of 1 if firm i is in the biopharma industry, and a value of 0 otherwise. Control variables include $\log(NA_{i,t})$, $(PPE/TA)_{i,t}$, $(Cash/TA)_{i,t}$, $(EBIT/TA)_{i,t}$, $(M/B)_{i,t}$, and $(Div/TA)_{i,t}$. Controls for cash and PPE are excluded when they are the dependent variable of interest. Year and firm fixed effects are included where indicated. Robust standard errors are given in parentheses, and standard errors are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

	Dependent Variable:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	$R\&D$	$R\&D$	PPE	PPE	$Cash$	$Cash$	$Debt$	$Debt$	$Net\,Debt$	$Net\,Debt$
$Act_t \times Biopharma_i$	−0.006	0.003	−0.017	−0.024	0.003	0.018	0.116***	0.027	0.106**	0.008
	(0.010)	(0.006)	(0.020)	(0.017)	(0.024)	(0.015)	(0.027)	(0.019)	(0.044)	(0.028)
$Biopharma_i$	0.020*		0.020		0.038		−0.060**		−0.089**	
	(0.010)		(0.022)		(0.023)		(0.025)		(0.043)	
Act_t	−0.013		−0.014		−0.039***		0.025*		0.065***	
	(0.008)		(0.011)		(0.014)		(0.014)		(0.025)	
Constant	0.056***	0.134***	0.295***	0.481***	0.140***	0.587***	0.168***	0.196***	0.027	−0.528***
	(0.009)	(0.024)	(0.015)	(0.033)	(0.016)	(0.067)	(0.015)	(0.071)	(0.027)	(0.116)
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Firm Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Year Fixed Effects	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1,494	1,317	2,461	2,002	2,461	2,002	2,422	2,002	2,422	2,002
Number of Firms	156	140	181	162	181	162	179	162	179	162
Adjusted R^2	0.051	0.862	0.007	0.829	0.035	0.739	0.062	0.736	0.045	0.770

other R&D-intensive firms.

At a broad level, innovative industries like biopharma have been subject to increased competitive pressures over time, through both regulation and technological breakthroughs that have allowed easier entry (such as the Human Genome Project and increasingly faster and cheaper sequencing technologies). We highlight how these changes in competition may affect important financial characteristics and risk over time, which may, in turn, affect the amount of funding that R&D-intensive firms are able to raise. For example, while increased competition may spur innovation through increased R&D investment, it also increases idiosyncratic and total volatility, potentially affecting the appeal of these firms to investors.

We do not view our framework as a complete characterization of the financial characteristics of important R&D-intensive industries such as the biopharma industry, but rather as a starting point for analyzing them. For example, an interesting extension would be to account for R&D projects that may change over time as a result of the discovery of new technology—this would affect the risk characteristics of R&D-intensive industries in ways that are not explicitly considered in the model. Another interesting extension would be to consider a portfolio of R&D projects, rather than the single R&D project in our analysis. In the context of our analysis, one benefit to adopting a portfolio approach is reducing the idiosyncratic risk in R&D due to the diversification provided by a portfolio of projects. While a number of advantages of creating a portfolio of R&D projects have been pointed out through the "megafund" idea of Fernandez, Stein and Lo (2012) and Fagnan, Fernandez, Lo, and Stein (2013), our analysis suggests that a portfolio of projects may change the effects of competition on innovation in important ways. Future work could extend our framework to evaluate these effects as well as the impact of additional frictions related to moral hazard or information asymmetries, and the new empirical predictions they generate.

References

1. Abel, Andrew B. "Optimal Debt and Profitability in the Tradeoff Theory." Working Paper, 2014.

2. Aghion, Philippe, Stefan Bechtold, Lea Cassar, and Holger Herz. The causal effects of competition on innovation: Experimental Evidence. No. w19987. National Bureau of Economic Research, 2014.

3. Aghion, Philippe, Nick Bloom, Richard Blundell, Rachel Griffith, and Peter Howitt. "Competition and Innovation: an Inverted-U Relationship." *The Quarterly Journal of Economics* 120, no. 2 (2005): 701-728.

4. Aghion, Phillipe, Mathias Dewatripont, and Patrick Rey. "Competition, Financial Discipline and Growth." *The Review of Economic Studies* 66, no. 4 (1999): 825-852.

5. Aghion, Philippe, Christopher Harris, Peter Howitt, and John Vickers. "Competition, imitation and growth with step-by-step innovation." *The Review of Economic Studies* 68, no. 3 (2001): 467-492.

6. Bali, Turan G., Nusret Cakici, Xuemin Sterling Yan, and Zhe Zhang. "Does Idiosyncratic Risk Really Matter?" *The Journal of Finance* 60, no. 2 (2005): 905-929.

7. Banks, Jeffrey Scot, and Joel Sobel. "Equilibrium Selection in Signaling Games." *Econometrica* 55, no. 3 (1987): 647-61.

8. Bergemann, Dirk, and Ulrich Hege. "The Financing of Innovation: Learning and Stopping." *RAND Journal of Economics* 36, no. 4 (2005): 719-752.

9. Bhattacharya, Sudipto, Jacob Glazer, and David EM Sappington. "Sharing Productive Knowledge in Internally Financed R&D Contests." *Journal of Industrial Economics* 39, no. 2 (1990): 187-208.

10. Bhattacharya, Sudipto, and Sergei Guriev. "Patents vs. trade secrets: Knowledge licensing and spillover." *Journal of the European Economic Association* 4, no. 6 (2006): 1112-1147.

11. Bloom, Nicholas, Mark Schankerman, and John Van Reenen. "Identifying Technology Spillovers and Product Market Rivalry." *Econometrica* 81, no. 4 (2013): 1347-1393.

12. Bolton, Patrick, Hui Chen, and Neng Wang. Debt, Taxes, and Liquidity. No. w20009. National Bureau of Economic Research, 2014.

13. Brown, James R., Steven M. Fazzari, and Bruce C. Petersen. "Financing Innovation and Growth: Cash Flow, External Equity, and the 1990s R&D Boom." *The Journal of Finance* 64, no. 1 (2009): 151-185.

14. Calomiris, Charles W., and Charles Milton Kahn. "The Role of Demandable Debt in Structuring Optimal Banking Arrangements." *American Economic Review* 81, no. 3 (1991): 497-513.

15. Cassiman, Bruno, and Reinhilde Veugelers. "In Search of Complementarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition." *Management Science* 52, no. 1 (2006): 68-82.

16. Caves, Richard E., Whinston, Michael D., and Mark A. Hurwitz, 1991, "Patent Expiration, Entry, and Competition in the U.S. Pharmaceutical Industry". *Brookings Papers on Economic Activity: Microeconomics* Vol. 1991, 1-66.

17. Cornaggia, Jess, Yifei Mao, Xuan Tian, and Brian Wolfe. "Does banking competition affect innovation?" *Journal of Financial Economics* 115, no. 1 (2015): 189-209.

18. DiMasi, Joseph A., and Henry G. Grabowski. "The cost of biopharmaceutical R&D: is biotech different?." *Managerial and Decision Economics* 28, no. 4-5 (2007): 469-479.

19. DiMasi, Joseph A., Henry G. Grabowski, and John Vernon. "R&D Costs, Innovative Output and Firm Size in the Pharmaceutical Industry." *International Journal of the Economics of Business* 2, no. 2 (1995): 201-219.

20. DiMasi, Joseph A., Ronald W. Hansen, and Henry G. Grabowski. "The Price of Innovation: New Estimates of Drug Development Costs." *Journal of Health Economics* 22, no. 2 (2003): 151-185.

21. DiMasi, Joseph A., Ronald W. Hansen, Henry G. Grabowski, and Louis Lasagna. "Cost of innovation in the pharmaceutical industry." *Journal of Health Economics* 10, no. 2 (1991): 107-142.

22. Fisher, Sara Ellison, Iain M. Cockburn, Zvi Griliches, and Jerry A. Hausman. "Characteristics of Demand for Pharmaceutical Products: An Examination of Four Cephalosporins." *RAND Journal of Economics* 28, no. 3 (1997): 426-446.

23. Fagnan, David E., Jose Maria Fernandez, Andrew W. Lo, and Roger M. Stein. "Can Financial Engineering Cure Cancer?" *The American Economic Review* 103, no. 3 (2013): 406-411.

24. Fernandez, Jose-Maria, Roger M. Stein, and Andrew W. Lo. "Commercializing biomedical research through securitization techniques." *Nature Biotechnology* 30, no. 10 (2012): 964-975.

25. Fama, Eugene F., and Kenneth R. French. "Common Risk Factors in the Returns on Stocks and Bonds." *Journal of Financial Economics* 33, no. 1 (1993): 3-56.

26. French, Kenneth R., G. William Schwert, and Robert F. Stambaugh. "Expected Stock Returns and Volatility." *Journal of Financial Economics* 19, no. 1 (1987): 3-29.

27. Gans, Joshua S., and Scott Stern. "Incumbency and R&D incentives: Licensing the Gale of Creative Destruction." *Journal of Economics & Management Strategy* 9, no. 4 (2000): 485-511.

28. Gans, Joshua S., and Scott Stern. "The Product Market and the Market for "Ideas": Commercialization Strategies for Technology Entrepreneurs." *Research Policy* 32, no. 2 (2003): 333-350.

29. Gans, Joshua S., David H. Hsu, and Scott Stern. "When Does Start-up Innovation Spur the Gale of Creative Destruction?" *RAND Journal of Economics* 33, no. 4 (2002): 571-586.

30. Gilbert, Richard J. "Competition and innovation." *Journal of Industrial Organization Education* 1, no. 1 (2006): 1-23.

31. Grabowski, Henry G. "Competition between generic and branded drugs." *Pharmaceutical innovation: incentives, competition, and cost-benefit analysis in international perspective* (2007).

32. Grabowski, Henry, and John Vernon. "Longer Patents for Lower Imitation Barriers: The 1984 Drug Act." *American Economic Review* 76, no. 2 (1986): 195-98.

33. Grabowski, Henry, and John Vernon. "A New Look at the Returns and Risks to Pharmaceutical R&D." *Management Science* 36, no. 7 (1990): 804-821.

34. Grabowski, Henry G., and John M. Vernon. "Brand Loyalty, Entry, and Price Competition in Pharmaceuticals after the 1984 Drug Act." *Journal of Law and Economics* 35, no. 2 (1992): 331-50.

35. Graham, John R., and Mark T. Leary. "A Review of Empirical Capital Structure Research and Directions for the Future." *Annual Review of Financial Economics* 3, no. 1 (2011): 309-345.

36. Grant, Robert M., and Judith J. Jordan. *Foundations of Strategy.* John Wiley & Sons, 2015.

37. Haddad, Valentin, Ho, Paul, and Erik Loualiche, "Detail Disagreement and Innovation Booms." Working Paper, 2014.

38. Hall, Bronwyn H., and Josh Lerner. "The Financing of R&D and Innovation." *Handbook of the Economics of Innovation* 1 (2010): 609-639.

39. Hannah, Leslie, and John Anderson Kay. *Concentration in modern industry: Theory, measurement and the UK experience.* London: Macmillan, 1977.

40. Hart, Oliver, and John Moore. "A Theory of Debt Based on the Inalienability of Human Capital." *The Quarterly Journal of Economics* 109, no. 4 (1994): 841-879.

41. Hart, Oliver, and John Moore. "Debt and Seniority: An Analysis of the Role of Hard Claims in Constraining Management." *The American Economic Review* 85, no. 3 (1995): 567-585.

42. Irvine, Paul J., and Jeffrey Pontiff. "Idiosyncratic Return Volatility, Cash Flows, and Product Market Competition." *Review of Financial Studies* 22, no. 3 (2009): 1149-1177.

43. Jensen, Michael C. "Agency cost of free cash flow, corporate finance, and takeovers." Corporate Finance, and Takeovers. *American Economic Review* 76, no. 2 (1986).

44. Jensen, Michael C., and William H. Meckling. "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure." *Journal of Financial Economics* 3, no. 4 (1976): 305-360.

45. Kogan, Leonid, and Dimitris Papanikolaou. "Growth Opportunities and Technology Shocks." *American Economic Review* 100, no. 2 (2010): 532-36.

46. Kogan, Leonid, and Dimitris Papanikolaou. "Growth Opportunities, Technology Shocks, and Asset Prices." *The Journal of Finance* 69, no. 2 (2014): 675-718.

47. Kreps, David M., and Robert B. Wilson. "Sequential Equilibria." *Econometrica* 50, no. 4 (1982): 863-94.

48. Langinier, Corinne, and GianCarlo Moschini. "The Economics of Patents: An Overview." (2002).

49. Lee, Cheng-Few, K. Thomas Liaw, and Shafiqur Rahman. "Impacts of market power and capital-labor ratio on systematic risk: a Cobb-Douglas approach." *Journal of Economics and Business* 42, no. 3 (1990): 237-241.

50. Lerner, Josh, Hilary Shane, and Alexander Tsai. "Do Equity Financing Cycles Matter? Evidence from Biotechnology Alliances." *Journal of Financial Economics* 67, no. 3 (2003): 411-446.

51. Lyandres, Evgeny and Palazzo, Berardino, Cash Holdings, Competition, and Innovation (March 14, 2014). Available at SSRN: http://ssrn.com/abstract=2017222.

52. Morellec, Erwan, Boris Nikolov, and Francesca Zucchi. "Competition, cash holdings, and financing decisions." Swiss Finance Institute Research Paper 13-72 (2014).

53. Myers, Stewart C. "Capital Structure." *Journal of Economic Perspectives* 15, no. 2 (2001): 81-102.

54. Myers, Stewart C., and Christopher D. Howe, 1997, *A Life-Cycle Financial Model of Pharmaceutical R&D.* Program on the Pharmaceutical Industry, Sloan School of Management, Massachusetts Institute of Technology.

55. Myers, Stewart C., and Nicholas S. Majluf. "Corporate Financing and Investment Decisions When Firms have Information that Investors do not Have." *Journal of Financial Economics* 13, no. 2 (1984): 187-221.

56. National Science Foundation, *National Patterns of R&D Resources: 1998*, by Steven Payson, NSF 99-335 (Arlington, VA, 1999).

57. Newey, Whitney K., and Kenneth D. West. "A Simple, Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix." *Econometrica* 55, no. 3 (1987): 703-08.

58. Officer, R. R. "The Variability of the Market Factor of the New York Stock Exchange." *The Journal of Business* 46, no. 3 (1973): 434-53.

59. Pástor, Ľuboš, and Pietro Veronesi. "Technological Revolutions and Stock Prices." *The American Economic Review* 99, no. 4 (2009): 1451-1483.

60. Pisano, Gary P. "The R&D Boundaries of the Firm: An Empirical Analysis." *Administrative Science Quarterly* 35, no. 1 (1990).

61. Ross, Stephen A. "The Determination of Financial Structure: the Incentive-signalling Approach." *Bell Journal of Economics* 8, no. 1 (1977): 23-40.

62. Schwert, G. William. "Why Does Stock Market Volatility Change over Time?" *The Journal of Finance* 44, no. 5 (1989): 1115-1153.

63. Stulz, Rene M. "Managerial Discretion and Optimal Financing Policies." *Journal of Financial Economics* 26, no. 1 (1990): 3-27.

64. Subrahmanyam, Marti G., and Stavros B. Thomadakis. "Systematic Risk and the Theory of the Firm." *The Quarterly Journal of Economics* 94, no. 3 (1980): 437-51.

65. Thakor, Richard T., Nicholas Anaya, Yuwei Zhang, Christian Vilanilam, and Andrew W. Lo. "Financial Risk and Return in the Biotech and Pharmaceutical Industries from 1930 to 2013". Working Paper, Sloan School of Management, Massachusetts Institute of Technology, 2015.

66. Tirole, Jean. *The Theory of Industrial Organization*. MIT press, 1988.

67. Zwiebel, Jeffrey. "Dynamic Capital Structure under Managerial Entrenchment." *The American Economic Review* 86, no. 5 (1996): 1197-1215.

Appendix A: Analysis of the Formal Theoretical Model

A.1 Actors, Preferences, and Asset Pricing

Consider a biopharmaceutical firm that faces a decision to undertake a staged R&D investment. There are two periods with three dates: $t = 0$, $t = 1$, and $t = 2$. At $t = 0$, the firm chooses an amount to invest in either assets-in-place (such as existing products) or in R&D (for new products). If it chooses to invest in an R&D project, the project has two stages. At $t = 0$, the first-stage investment is made. At $t = 1$, the second-stage investment is made.

At both of these dates, the firm may need to raise capital and can choose between issuing equity and debt. This external financing is raised in an environment of adverse selection. Specifically, there are two types of firms: good firms and lemons. The common prior is that the probability of a randomly-chosen firm being good is $g \in (0.5, 1)$ and being a lemon is $1 - g$.[28] The lemons are firms that lack the ability to produce R&D products, so their R&D investment produces no payoffs and their assets decline in value over time and also produce no cash-flows.[29] The good firms are described below. The firm *privately* knows at $t = 0$ whether it is good or a lemon. Given this private information, we will model this as a game in which the informed firm moves first with its capital structure decision and how much financing to raise for R&D (and when to raise it). The uninformed capital market reacts to the firm's choice and makes Bayesian rational inferences about the firm's payoffs, which then results in prices for the firm's securities.

At the final date, $t = 2$, all payoffs are realized, and shareholders and bondholders are paid off.

The expected rate of return on an asset with systematic risk loading β is $K(\beta)$. The riskfree rate for a single period is $r > 0$ and is intertemporally constant. Systematic risk is priced, and idiosyncratic risk is not. For example, assume that there is a linear factor model for returns:

$$R_i = r + \beta_i \mathbf{\Gamma} + \varepsilon_i \tag{A.1}$$

where $\mathbf{\Gamma}$ represents a vector of returns of systematic factors, β_i is a vector of loadings on those factors for asset i, r is the riskless rate of return, and ε_i is a mean-zero error term that represents the idiosyncratic portion of the return. The expected return on any such asset is thus given by:

$$K(\beta) \equiv \mathbb{E}[R_i] = r + \beta_i \mathbb{E}[\mathbf{\Gamma}]. \tag{A.2}$$

The CAPM or Fama-French 3-factor model would be an example of such a model. Thus, securities are priced so that investors who provide financing to the firm receive exactly the expected return commensurate with the (priced) risk in the security.

[28] The lower bound on g is to avoid a corner solution by ensuring that there are sufficiently many good firms to allow financing to be raised.

[29] This could be due to mismanagement or outright fraud. The lemons are able to produce what appears to be sucessful first-stage R&D results, but the R&D is still worthless for these firms since they are not able to make it produce any cash flows.

A.2 Investment Choices and the Effect of Competition

For simplicity, the existing products/assets of the firm have only systematic risk, with $\beta = 1$, whereas R&D has only idiosyncratic risk with $\beta = 0$ (e.g. Pastor and Veronesi (2009)).[30] Let $A > 0$ denote the firm's investment in existing products/assets-in-place. and $R > 0$ its investment in R&D. Given managerial capacity constraints, we take the total investment size to be fixed at I. Thus, $A + R = I$, so the firm invests a certain proportion of its capital in assets-in-place and the remaining proportion in R&D. Our goal is to examine how A and R are determined.

There are two states of the macroeconomy: an "up" state and a "down" state. The up state occurs with probability p and the down state occurs with probability $1 - p$. When the up state occurs, the firm's existing products pay off $x_H(A)$, and when the down state occurs they pay off $x_L(A)$, with $x_H(A) > x_L(A)\ \forall\, A > 0$. That is, the payoff from existing products is perfectly correlated with the state of the economy, so the single-period discount rate applicable to these payoffs is $K(1) \equiv K$. It is assumed that the NPV of investing in assets-in-place is non-negative, even if the down-state occurs: $x_L(A)[1 + K]^{-2} \geq A\ \forall A$. We impose the standard assumptions on the production function $x\,(A)$:

$$\partial x_H/\partial A > \partial x_L/\partial A > 0, \quad \partial^2 x_H/\partial A^2 < 0,$$

$$\partial^2 x_L/\partial A^2 < 0, \quad \left|\partial^2 x_H/\partial A^2\right| > \left|\partial^2 x_L/\partial A^2\right|, \tag{A.3}$$

We now model the effect of product-market competition. If the degree of competition is $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$, then a competitor arrives with probability θ and if this happens, the firm's profitability on existing products declines—thus, a higher θ means greater product-market competition.[31] For simplicity, we assume that when a competitor enters, the payoff of assets-in-place in the up-state becomes $x_L(A)$, an effect analogous to Bertrand competition.[32]

[30] As noted, R&D involves new projects that are one-off stand-alone investments by individual firms and are the resulting products also patent-protected, and hence uncorrelated with the economy. Existing products contain systematic risk because they involve similar investments by many other firms.

[31] In our model, changes in competition θ can be interpreted as structural changes in the industry or other changes in competition that are exogenous to the individual firm. Important drivers of competition to industries such as biopharma are exogenous technology or regulatory shocks that lower entry costs. For example, the Human Genome Project represented a technology shock that was plausibly exogenous to any individual firm's decision, and it led to the entry of numerous small biotech firms into the industry (see Thakor et. al. (2015)). Another example is the Hatch-Waxman Act, which was a source of exogenous variation in competition for the biopharma industry, and something we use for identification purposes later in our analysis. However, since R&D by incumbents can also affect the degree of competition, some portion of the degree of competition is endogenous (e.g. Gans and Stern (2000)). Our empirical tests are designed to tackle this potential endogeneity.

[32] In other words, the incumbent firm and the competitor would each set their prices for existing products lower in order to undercut each other, thus reducing profitability. We model this directly through a reduction in profitability. Although not necessary for the analysis, we could assume that the present value of $x_L(A)$ is A, i.e., that competition reduces the NPV of existing assets to zero. This would correspond to the situation in Bertrand competition, where firms set their prices equal to their marginal costs

Investment in R&D involves two phases. At $t = 0$, the firm makes its first-stage R&D investment R. Then, if it observes at $t = 1$ that the successful state has occurred for R&D, it must invest a larger additional amount $\hat{\omega}R$, $\hat{\omega} > 1$, in order to realize the payoff conditional on success. This larger second investment reflects the escalating resource commitments for subsequent clinical R&D trials that biopharma firms face (see DiMasi, et al. (1991)). Absent this second-stage investment, the R&D payoff at $t = 2$ is zero.

If the firm invests R in R&D at $t = 0$, then at $t = 1$ it becomes publicly known whether the first-stage R&D was very successful, modestly successful, or failed. The probability of the first-stage R&D being very successful is $q_+ \in (0, 1)$, the probability of it being modestly successful is $q_- \in (0, 1)$, and the probability of failure is $1 - q_+ - q_-$. However, this observation does not resolve the uncertainty about whether the firm is good or a lemon, since the lemon firm can be in each of these three observable first-stage R&D outcome states as well, just like the good firm. But if the firm is truly a lemon, then the second-stage R&D payoff is zero at $t = 2$ regardless of the first-stage R&D outcome at $t = 1$. If the firm is good then the R&D payoff at $t = 2$ is a random variable $\tilde{y}$, where $\tilde{y}$ is zero almost surely if the first-stage R&D fails at $t = 1$, has a probability density ξ_+ if the first-stage R&D is very successful at $t = 1$, and a probability density ξ_- if the first-stage R&D is modestly successful at $t = 1$. We assume that ξ_+ first-order stochastically dominates ξ_-. The expected payoffs are:

$$\int \tilde{y}\xi_+ d\tilde{y} = y_+(R) + B > 0, \tag{A.4}$$

$$\int \tilde{y}\xi_- d\tilde{y} = y_-(R) + B > 0, \tag{A.5}$$

where $y_+(R) > y_-(R)\ \forall R > 0$, $y_+(0) = y_-(0) = 0$, and $B > 0$ is a non-contractible (knowledge) benefit of R&D to the insiders of the firm that cannot be verified and pledged to investors to make payments. We interpret B broadly to represent intangible payoffs that do not necessarily produce cashflows, such as learning benefits for employees, generation of non-commercializable basic research knowledge, or potential payoffs that may be expected to occur beyond the investment horizons of investors. We assume that the larger the investment in R&D, the larger the expected payoff:

$$\partial y_+/\partial R > 0, \quad \partial y_-/\partial R > 0,$$

$$\partial^2 y_+/\partial R^2 < 0, \quad \partial^2 y_-/\partial R^2 < 0. \tag{A.6}$$

The R&D payoff distribution is given in *Figure A1*.

We assume that R&D output is patent-protected and hence immune to competitive pressures. Thus, the arrival of the competitor has no impact on the firm's R&D payoff.[33] In other words, changes in θ affect the profitability of existing assets (which have largely exhausted their patent protection and are thus vulnerable to competitive pressures) relative to new, patent-protected drugs

[33]Of course, when the patent expires, these products become part of the firm's assets-in-place and are subject to losses in profits due to competitive entry.

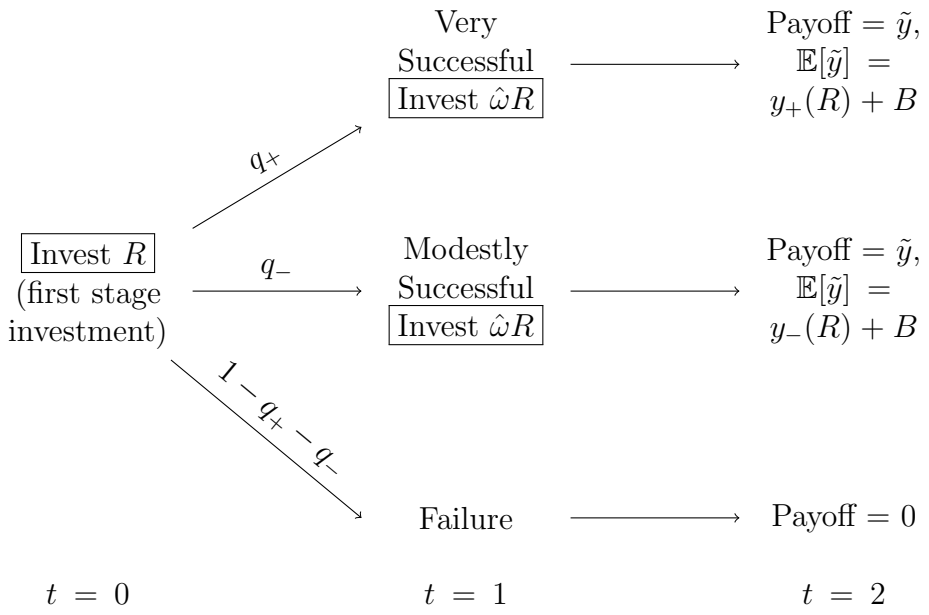


Figure A1: R&D Payoff Distribution Over Time

that have greater immunity to competitive pressures.

The payoffs of assets-in-place and R&D are taxable at a rate of $T \in (0, 1)$. We assume that the cash flows (i.e. the pledgeable portion of the payoff) of the R&D investment of the good firm creates value (and thus is positive NPV at $t = 0$ to the firm's insiders as well as investors), so:

$$[q_+ y_+ + q_- y_-] [1 + r]^{-2} (1 - T) > R + \hat{\omega} R [1 + r]^{-1} \quad \forall R > 0. \tag{A.7}$$

Note that, since R&D contains only idiosyncratic risk (hence $\beta = 0$) each side is discounted by the riskfree rate $1 + r$. We further assume that

$$\hat{g} y_- [1 + r]^{-1} (1 - T) < \hat{\omega} R, \tag{A.8}$$

$$y_- [1 + r]^{-1} (1 - T) + B > \hat{\omega} R + R, \tag{A.9}$$

$$B < \hat{\omega} R. \tag{A.10}$$

where $\hat{g}$ is the posterior belief of investors that the firm is good, conditional on a good signal being received by bondholders; $\hat{g}$ will be expressed explicitly later. Condition (A.8) implies that investors will be unwilling to provide financing at $t = 1$ if the R&D is discovered to have either failed or is only modestly successful, even if the bondholders' signal is good. Condition (A.9) implies that the firm's insiders will wish to invest $\hat{\omega} R$ at $t = 1$ even if the R&D is discovered to be modestly successful, and will also view this investment as beneficial at $t = 0$, taking into account the initial investment of R. And condition (A.10) ensures that the value of the non-contractible benefits to insiders is not so large as to justify an investment with no cash-flow payoff.

A.3 Financing Choices

The firm has no internal funds available at $t = 0$. Therefore, in order to finance the existing product line and R&D, it raises all the necessary financing by issuing debt and equity at $t = 0$ and $t = 1$, which then determines its capital structure.

Equity holders will be paid off at $t = 2$. In order to raise equity, the firm's initial shareholders (who we treat as insiders and who have no wealth of their own to invest) must give up ownership $\alpha \in (0, 1)$ in order to raise the necessary capital. At any date ($t = 0$ or $t = 1$), shareholder unanimity is needed to approve a capital raising decision. Thus, at $t = 0$ this decision is made to maximize the wealth of the insiders (initial owners) plus the value of their non-contractible benefits, B. At $t = 1$, this decision will require those who became shareholders at $t = 0$ to also approve. Those new shareholders are pure investors who do not get any of the non-contractible benefits of R&D enjoyed by insiders, benefits that include knowledge generation, learning, etc.

If the firm issues debt, the face value of debt to be repaid at $t = 2$ is F. The initial debt financing raised is D. Although bondholders cannot distinguish between good firms and lemons at $t = 0$, they receive a noisy signal ϕ at $t = 1$ that indicates whether the firm is good or a lemon. The probability distribution of ϕ is:

$$\Pr(\phi = \text{good} \mid \text{firm is a lemon}) = \Pr(\phi = \text{lemon} \mid \text{firm is a lemon}) = \delta \in (0.5, 1). \tag{A.11}$$

Upon receiving their signal, the bondholders can choose to wait until $t = 2$ to be paid, or to demand early repayment at $t = 1$ at a cost $c > 0$. If repayment occurs at $t = 1$ the bondholders are paid $F_1 \equiv F[1 + r]^{-1} < F$. In equilibrium, since the firm produces no cash flows at $t = 1$, the firm is liquidated to meet any repayment at $t = 1$ (if this is demanded) because it cannot meet the face value owed to bondholders. This modeling setup for debt parallels that of Calomiris and Kahn (1991). If the firm is a good firm, but is erroneously liquidated at $t = 1$ and the R&D is stopped, then all that can be recovered is the present value of the smallest payoff from the assets-in-place, $x_L(A)[1 + r]^{-1}$, plus any cash on hand, where we discount at the riskless rate because liquidation is analogous to making the asset payoff the minimum in all states. If the firm is a lemon, then only the salvage value of assets-in-place can be recovered. Let this salvage value be $S \in (0, A)$. The value of the assets recovered in liquidation at $t = 1$ can only be determined after the liquidation is completed. We assume that:

$$\frac{[1 - g][1 - \delta]S}{g\delta + [1 - g][1 - \delta]} < c < \frac{[1 - g]\delta}{[1 - g]\delta + [1 - \delta]g}. \tag{A.12}$$

We will show that (A.12) is sufficient to ensure that bondholders will liquidate the firm when $\phi =$ lemon, but not when $\phi =$ good. We assume that all debt payments are tax deductible at the corporate tax rate T. For debt to be tax deductible, the face value of the debt issued at $t = 0$

cannot exceed the total amount of financing raised at $t = 0$.[34] The variables D, F, and α will all be endogenously determined.

We will assume henceforth that certain parametric restrictions hold:

$$\delta < \bar{\delta} \in (0.5, 1), \quad B > \bar{B}, \tag{A.13}$$

where $\bar{\delta}$ is an upper bound and $\bar{B}$ is a lower bound. Thus, (A.13) implies that the non-contractible benefit of R&D to insiders is sufficiently high. The upper bound on δ means that there is sufficient noise in the bondholders' signal.

A.4 Analysis of the Model

We now present out analysis of the model. Throughout the analysis, we will focus on the good type of firms. The reason is that the lemons will always mimic the strategy of the good type in equilibrium, since acting otherwise would unambiguously reveal them. Nonetheless, the presence of the lemons is needed for the liquidation strategy of the bondholders to be subgame perfect.

We begin by presenting some preliminary results in which we take as a given A^* and R^*, the investments by the firm in assets-in-place and R&D, as well as a conjectured face value of debt issued at $t = 0$. We subsequently verify these equilibrium values. Because taxes play no role in the first two results, we set $T = 0$ without loss of generality for now. The equilibrium concept for the choices (and beliefs) at $t = 0$ is sequential equilibrium (Kreps and Wilson (1982)). The equilibrium we focus on also satisfies the universal divinity refinement of Banks and Sobel (1987); details of the proofs of the characterized outcomes satisfying the universal divinity refinement are available upon request.

Lemma 1: *Fix the optimal values of investments A^* and R^* by the firm in assets-in-place and R&D, respectively. Suppose the firm issues debt with face value $F = x_L(A^*)$. Then it will be subgame perfect for the bondholders to liquidate the firm at $t = 1$ if their signal is $\phi =$ lemon, and allow it to continue if their signal is $\phi =$ good.*

Proof: Suppose the bondholders' signal at $t = 1$ says $\phi =$ lemon. Let

$$\hat{g}_l = \Pr(\text{firm is good} \mid \phi = \text{lemon}) = \frac{[1-\delta]g}{[1-\delta]g + [1-g]\delta}. \tag{A.14}$$

For the bondholders to wish to liquidate the firm at $t = 1$, it must be true that:

$$[1 - \hat{g}_l]\, S + \hat{g}_l \left[x_L(A^*)\,[1+r]^{-1}\right] - c > \hat{g}_l x_L(A^*)\,[1+r]^{-1}, \tag{A.15}$$

[34] This is meant to capture the IRS limit on how much of a firm's financing can count as debt for tax purposes.

where the left-hand side of (A.15) is the expected value of what the bondholders collect at $t = 1$ and the right-hand side is the expected present value of what the bondholders collect if they wait until $t = 2$. We see that (A.15) simplifies to

$$\left\{ \frac{[1-g]\delta}{[1-\delta]g + [1-g]\delta} \right\} S > c, \tag{A.16}$$

which we know holds by (A.12). Now suppose the bondholders' signal at $t = 1$ is $\phi =$ good. Let $\hat{g}$ be the posterior belief of the bondholders that the firm is good after having observed this signal. Then for the bondholders to not liquidate the firm, we need

$$[1-\hat{g}]\, S + \hat{g}\left[x_L\left(A^*\right)[1+r]^{-1}\right] - c < \hat{g} x_L\left(A^*\right)[1+r]^{-1}, \tag{A.17}$$

where

$$\hat{g} = \frac{\delta g}{\delta g + [1-\delta][1-g]} < c. \tag{A.18}$$

Substituting (A.18) into (A.17), we see that we need

$$\frac{[1-\delta][1-g]S}{\delta g + [1-\delta][1-g]} < c, \tag{A.19}$$

which holds by (A.12). ■

Lemma 2: *Fix the optimal values of investments A^* and R^* by the firm in assets-in-place and R&D, respectively. Suppose the firm issues debt with face value $F = x_L\left(A^*\right)$. Then, for B large enough, it will prefer to raise at $t = 0$ the present value of the second-stage financing that will be needed at $t = 1$, and hold it as cash (invested it in the riskless asset) rather than wait until $t = 1$ to raise the financing.*

Proof: Given this F, it is clear that in the down state of the economy for the assets-in-place, (A.8) implies that the firm will be unable to raise second-stage financing for its R&D at $t = 1$ if the R&D is modestly successful and the expected R&D payoff at $t = 2$ is $y_-\left(R^*\right)$. We will compare the net benefit to the insiders from issuing equity at $t = 0$ to raise $\hat{\omega}R[1+r]^{-1}$ in financing with the net benefit to them of issuing equity at $t = 1$ to raise the necessary financing. Consider first the case of raising financing at $t = 0$, and let $\hat{\alpha} \in (0, 1)$ be the fraction of ownership given up in order to raise $\hat{\omega}R[1+r]^{-1}$. Thus, the competitive pricing condition implies

$$\hat{\omega}R[1+r]^{-1} = \hat{\alpha} g V_E, \tag{A.20}$$

where we define $V_E = \left[\delta\Omega_0 + [1-\delta]\hat{\omega}R[1+r]^{-1}\right]$ and (suppressing the arguments of functions):

$$\Omega_0 \equiv [1+r]^{-1}\left[q_+ y_+ + q_- y_-\right] + p[1-\theta]\left[x_H - x_L\right][1+K]^{-2} + \left[1 - q_+ - q_-\right]\hat{\omega}R[1+r]^{-1}. \tag{A.21}$$

So V_E is the true value of the good firm's equity at $t = 0$ as assessed by the insiders. Note that Ω_0 can be understood as follows. The first term is the expected present value of the R&D payoff, the second term is present value of assets-in-place (where we recognize that $F = x_L$) and the third term is the additional R&D financing raised at $t = 0$ that remains idle at $t = 1$ because the R&D fails the first-stage. The market value of this equity is $g\delta V_E$ because the market assesses the probability of the firm being good as g, and δ is the probability that a good firm will be allowed to continue. Note that $1 - \delta$ is the probability that a good firm will be liquidated, in which case $x_L + \hat{\omega}R$ is recovered. Since $F = x_L$, the shareholders only collect $\hat{\omega}R$, with present value $\hat{\omega}R[1+r]^{-1}$ at $t = 0$. This explains the $[1 - \delta]\,\hat{\omega}R[1 + r]^{-1}$ term in V_E in (A.20). Thus,

$$\hat{\alpha} = \frac{\hat{\omega}R[1 + r]^{-1}}{gV_E}. \tag{A.22}$$

The net wealth of the insiders plus the non-contractible benefits from raising extra financing at $t = 0$ is:

$$NW_0 = [1 - \hat{\alpha}]\,V_E + \delta\,[q_+ + q_-]\,B, \tag{A.23}$$

where $\delta\,[q_+ + q_-]$ is the probability that the extra R&D investment will be made at $t = 1$ and the R&D will be continued. Thus, substituting (A.22) into (A.23):

$$\begin{aligned} NW_0 &= V_E - \hat{\omega}R[1 + r]^{-1}g^{-1} + \delta\,[q_+ + q_-]\,B \\ &= \delta\Omega_0 - \hat{\omega}R[1 + r]^{-1}\left\{g^{-1} - [1 - \delta]\right\} + \delta\,[q_+ + q_-]\,B. \end{aligned} \tag{A.24}$$

Now consider financing at $t = 1$. There are two possible states related to the assets-in-place: the up-state and the down-state. Moreover, financing will only be raised if: (i) the bondholders' signal ϕ = good, and (ii) the R&D has been discovered to be very successful. Given (A.8) and the need for approval from those who became new shareholders at $t = 0$ by purchasing the equity issued by the firm then, it is clear that no financing can be raised at $t = 1$ if the R&D is only modestly successful. Now, if ϕ = good, the posterior belief of the bondholders about the firm's type becomes

$$\hat{g} = \Pr(\text{firm is good} \mid \phi = \text{good}) = \frac{\delta g}{\delta g + [1 - \delta][1 - g]}. \tag{A.25}$$

Let α_u be the ownership the firm must surrender at $t = 1$ in the up-state to raise $\hat{\omega}R$ then. This means

$$\alpha_u\hat{g}\left\{y_+ + [x_H - x_L]\,[1 + r][1 + K]^{-1}\right\}[1 + r]^{-1} = \hat{\omega}R, \tag{A.26}$$

which implies that

$$\alpha_u = \frac{\hat{\omega}R}{\hat{g}V_u^1}, \tag{A.27}$$

where

$$V_u^1 \equiv \left\{y_+ + [x_H - x_L]\,[1 + r][1 + K]^{-1}[1 + r]^{-1}\right\}. \tag{A.28}$$

If α_d is the ownership the firm must surrender at $t = 1$ in the down-state to raise $\hat{\omega}R$, then $\alpha_d \hat{g} y_+ [1+r]^{-1} = \hat{\omega}R$, which implies

$$\alpha_d = \frac{\hat{\omega}R}{\hat{g}V_d^1}, \tag{A.29}$$

where

$$V_d^1 \equiv y_+ [1+r]^{-1}. \tag{A.30}$$

For the firm's insiders at $t = 0$, their expected wealth from pursuing this strategy is

$$\begin{aligned} \mathbb{E}[NW_1] &= \delta \left\{ q_+ p[1-\theta] [1-\alpha_u] V_u^1 + [1-q_+] [x_H - x_L] [1+K]^{-1} \right\} \\ &\quad + \delta \left\{ q_+ [1 - p[1-\theta]] [1-\alpha_d] V_d^1 + q_+ B \right\}, \end{aligned} \tag{A.31}$$

where we note that the non-contractible rent B is available to insiders only if the R&D is very successful. Expressing $\hat{V}_u^1$ and $\hat{V}_d^1$ as the date-0 present values of V_u^1 and V_d^1 respectively, we can write

$$\hat{V}_u^1 = \left\{ y_+ + \left[x_H - x_L [1+r]^2 [1+K]^{-2} \right] \right\} [1+r]^{-2}, \tag{A.32}$$

$$\hat{V}_d^1 = y_+ [1+r]^{-2}. \tag{A.33}$$

Simplifying (A.31) by substituting (A.27) and (A.29), we get

$$\begin{aligned} \mathbb{E}[NW_1] &= \delta \left\{ q_+ p[1-\theta] V_u^1 - q_+ p[1-\theta] \hat{\omega} R \hat{g}^{-1} + q_+ [1 - p[1-\theta]] V_d^1 \right\} \\ &\quad + \delta \left\{ -q_+ [1 - p[1-\theta]] \hat{\omega} R \hat{g}^{-1} + q_+ B + [1-q_+] [x_H - x_L] [1+K]^{-1} \right\}. \end{aligned} \tag{A.34}$$

Simplifying, we can write the present value (at $t = 0$) of $\mathbb{E}[NW_1]$ as:

$$\begin{aligned} \hat{\mathbb{E}}[NW_1] &= \delta \left\{ q_+ p[1-\theta] \hat{V}_u^1 + q_+ [1 - p[1-\theta]] \hat{V}_d^1 \right\} \\ &\quad + \delta \left\{ -q_+ [1+r]^{-1} \hat{\omega} R \hat{g}^{-1} + q_+ B + [1-q_+] [x_H - x_L] [1+K]^{-2} \right\}. \end{aligned} \tag{A.35}$$

The firm's insiders will prefer to raise the extra R&D financing at $t = 0$ rather than at $t = 1$ if $NW_0 > \hat{\mathbb{E}}[NW_1]$, where NW_0 is defined in (A.24). Upon simplification, this condition becomes

$$q_- \left[B + y_- [1+r]^{-2} \right] > \hat{\omega} R [1+r]^{-1} \left\{ \frac{1}{g\delta + [1-\delta][1-g]} - \frac{1-\delta}{\delta} - [1-q_-] \right\}, \tag{A.36}$$

which holds for B large enough. ■

Let F be the face value of debt if the bondholders wait until $t = 2$ to be repaid, and let F_1 be the face value if they ask to be repaid at $t = 1$. We can now write down the firm's maximization problem, taking as a given that it will raise $R + \hat{\omega} R [1+r]^{-1}$ for its R&D and A for its assets-in-place through a mix of debt and equity financing at $t = 0$. The value of equity as assessed by insiders at

$t = 0$ is similar to the way it was expressed in the proof of Lemma 2:

$$\begin{aligned} V_E &= [1-T]\delta\left\{[1+r]^{-2}\left[q_+ y_+(R) + q_- y_-(R)\right] + p[1-\theta]\left[x_H(A) - F\right][1+K]^{-2}\right. \\ &\quad + [1-p[1-\theta]]\left[x_L(A) - F\right][1+K]^{-2} + \left[1 - q_+ - q_-\right]\hat{\omega}R[1+r]^{-1}\Big\} \\ &\quad + [1-T][1+r]^{-1}[1-\delta]\max\left\{0, \hat{\omega}R + x_L(A)[1+r]^{-1} - F_1\right\}, \end{aligned} \tag{A.37}$$

where we recognize that a good firm will be liquidated at $t = 1$ with probability $1 - \delta$ by the bondholders, and the value of equity in this case will be equivalent to a call option on the liquidation value of the assets with a strike price equal to what bondholders are owed, F_1. Note that the risk associated with the noise in the bondholders' signal is idiosyncratic.

Now if α is the fraction of equity surrendered in addition to F, the face value of debt to raise $A + R + \hat{\omega}R[1+r]^{-1}$ at $t = 0$, then α satisfies:

$$\alpha V_E\left(A^*, R^*\right) = A^* + R^* + \hat{\omega}R^*[1+r]^{-1} - D, \tag{A.38}$$

where D is the amount of debt financing raised at $t = 0$. So D satisfies:

$$D = \mathrm{PV}\left\{g\left[\delta\mathbb{E}_2\left[F\right] + [1-\delta]\min\left\{F_1, x_L\left(A^*\right)[1+r]^{-1} + \hat{\omega}R^*\right\}\right] + [1-g]\delta S[1+r]^{-1}\right\}, \tag{A.39}$$

where PV is the present value operator and (A.39) reflects the fact that if the firm is good (probability g), then bondholders allow it to continue with probability δ, yielding an expected payoff at $t = 2$ of $\mathbb{E}_2[F]$ to the bondholders. If the good firm is liquidated, the bondholders receive $\min\left\{F_1, x_L\left(A^*\right)[1+r]^{-1} + \hat{\omega}R^*\right\}$, whereas if the bad firm is liquidated, they receive S.

The insiders of the firm choose the investments A and R and the mix of debt and equity to finance them by solving the following problem:

$$\begin{aligned} &\max_{(A,R)\in\mathbb{R}^2,\, \alpha\in[0,1],\, F\geq 0} \left\{[1-\alpha]V_E + \mathbb{E}[B]\right\} \\ &\qquad \text{subject to} \quad \text{(A.38) and (A.39)}. \end{aligned} \tag{A.40}$$

Here $\mathbb{E}[B]$ is the expected value of the insiders' non-contractible benefits, where the expectation depends on the firm's chosen capital structure.

We now establish a result about the firm's capital structure choice.

Proposition 1: *For any given A^* and R^*, the firm will set $F = x_L\left(A^*\right)$, $F_1 = F[1+r]^{-1}$.*

Proof: Suppose counterfactually that $F > x_L\left(A^*\right)$. Then we will establish that the bondholders will find it subgame perfect to liquidate the firm at $t = 1$ regardless of ϕ. To see this, suppose $\phi =$ good. Then, the bondholders' expected payoff at $t = 1$ if they liquidate the firm is $\hat{g}F + [1-\hat{g}]\,S$ since $x_L\left(A^*\right)[1+K]^{-2} \geq A^*$, so $x_L\left(A^*\right)[1+K]^{-1} + \hat{\omega}R^* > A^* + R^*$, given $\hat{\omega} > 1$ and $F < A^* + R^*$.

If they allow the firm to continue, then their expected payoff is

$$\hat{g}\left\{x_L\left(A^*\right)+\int_0^{F-x_L(A^*)}\tilde{y}\xi_+dy\right\}, \tag{A.41}$$

if the R&D is very successful. Since $F > x_L\left(A^*\right)$, it is clear that

$$F > x_L\left(A^*\right)+\int_0^{F-x_L(A^*)}\tilde{y}\xi_+dy, \tag{A.42}$$

so the bondholders will liquidate the firm. If $\phi =$ lemon, the bondholders' payoff with liquidation is

$$g_l F+\left[1-g_l\right]S, \tag{A.43}$$

and with continuation it is

$$g_l\left\{x_L\left(A^*\right)+\int_0^{F-x_L(A^*)}\tilde{y}\xi_+dy\right\}. \tag{A.44}$$

Clearly, the liquidation payoff is higher. Given this, it is not optimal for the insiders at $t=0$ to set $F > x_L\left(A^*\right)$.

Now suppose that $F < x_L\left(A^*\right)$. Then given Lemma 1, we know that the firm will be liquidated if $\phi =$ lemon and continued if $\phi =$ good. Now, when $F < x_L\left(A^*\right)$, (A.37) can be written as:

$$\begin{aligned}\hat{V}_E &= [1-T]\delta\big\{[1+r]^{-2}\left[q_+y_+ + q_-y_-\right]+p[1-\theta]\left[x_H(A)-F\right][1+K]^{-2}\\ &\quad +[1-p[1-\theta]]\left[x_L(A)-F\right][1+K]^{-2}+\left[1-q_+-q_-\right]\hat{\omega}R[1+r]^{-1}\big\}\\ &\quad +[1-T][1+r]^{-1}[1-\delta]\left[\hat{\omega}R+x_L(A)[1+r]^{-1}-F_1\right].\end{aligned} \tag{A.45}$$

Thus, the total value of the insiders' claim plus non-contractible benefits is:

$$[1-\alpha]\hat{V}_E+\left[q_++q_-\right]B, \tag{A.46}$$

where

$$\alpha=\frac{A+R[1+\omega]-D}{g\hat{V}_E}, \tag{A.47}$$

$$\omega\equiv\hat{\omega}[1+r]^{-1}, \tag{A.48}$$

and using (A.39), we can write

$$D=gF[1+r]^{-2}+[1-g]\delta S[1+r]^{-1}, \tag{A.49}$$

where we recognize that if the firm is good, then the bondholders receive either $F_1=F[1+r]^{-1}$ at $t=1$, or F at $t=2$, so this payoff is riskless and has present value $F[1+r]^{-2}$ at $t=0$. If the firm is a lemon and the bondholders liquidate at $t=1$ (joint probability $[1-g]\delta$), then their payoff

is S, with present value $S[1+r]^{-1}$. Substituting (A.47) and (A.49) into (A.45) yields the insiders' objective function:

$$\begin{aligned}\Omega &= \hat{V}_E - \alpha\hat{V}_E + [q_+ + q_-]\,B \\ &= \hat{V}_E - \frac{\left\{A + R[1+\omega] - gF[1+r]^{-2} - [1-g]\delta S[1+r]^{-1}\right\}}{g} + [q_+ + q_-]\,B \\ &= \hat{V}_E - \frac{\left\{A + R[1+\omega] - [1-g]\delta S[1+r]^{-1}\right\}}{g} + F[1+r]^{-2} + [q_+ + q_-]\,B \qquad \text{(A.50)}\end{aligned}$$

Thus,

$$\frac{\partial\Omega}{\partial F} = -[1-T]\delta[1+K]^{-2} + [1+r]^{-2} > 0. \qquad \text{(A.51)}$$

Thus, the firm will wish to increase F when $F < x_L(A^*)$. Since $F > x_L(A^*)$ has been ruled out, it must be true that $F = x_L(A^*)$. ■

Next we examine how the firm determines A^* and R^*, taking as given the capital structure choice just derived. That is, the firm solves:

$$(A, R) \in \arg\max_{\mathbb{R}^2} \Omega, \qquad \text{(A.52)}$$

with $A + R = I$. The following result can now be proved.

Proposition 2: *At $t = 0$, There is a unique optimal level of investment in assets-in-place, A^*, and a unique optimal level of investment in R&D, R^*, with $\partial A^*/d\theta < 0$ and $\partial R^*/d\theta > 0$.*

Proof: The first-order condition that A^* satisfies is $\partial\Omega/\partial A = 0$. Recognizing that $A + R = I$ and using (A.45) for $\hat{V}_E$, we can write the first-order condition as

$$\begin{aligned}&[1-T]\delta\Bigg\{[1+r]^{-2}\left[\left[\frac{\partial y_+}{\partial R}\right]\left[\frac{\partial R}{\partial A}\right]q_+ + \left[\frac{\partial y_-}{\partial R}\right]\left[\frac{\partial R}{\partial A}\right]q_-\right] + p[1-\theta]\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right][1+K]^{-2} \\ &+ [1 - q_+ - q_-]\,\omega\left[\frac{\partial R}{\partial A}\right]\Bigg\} + [1-T][1-\delta]\omega\left[\frac{\partial R}{\partial A}\right] - \frac{1 + \left[\frac{\partial R}{\partial A}\right][1+\omega]}{g} = 0 \qquad \text{(A.53)}\end{aligned}$$

Since $\partial R/\partial A = -1$, we can write (A.53) as:

$$\begin{aligned}&[1-T]\delta\Bigg\{-[1+r]^{-2}\left[q_+\left[\frac{\partial y_+}{\partial R}\right] + q_-\left[\frac{\partial y_-}{\partial R}\right]\right] + p[1-\theta]\left[\frac{\partial x_H}{\partial A} - \frac{\partial x_L}{\partial A}\right][1+K]^{-2} - [1 - q_+ - q_-]\,\omega\Bigg\} \\ &-[1-T][1-\delta]\omega - \omega g^{-1} = 0 \qquad \text{(A.54)}\end{aligned}$$

The second-order condition for a unique maximum is $\partial^2\Omega/\partial A^2 < 0$, which translates to

$$[1-T]\delta[1+K]^{-2}p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2} - \frac{\partial^2 x_L}{\partial A^2}\right] < 0, \qquad \text{(A.55)}$$

given (A.3). To show that $dA^*/d\theta < 0$, we totally differentiate the first-order condition (A.53):

$$[1-T]\delta[1+K]^{-2}\left\{-p\left[\frac{\partial x_H}{\partial A}-\frac{\partial x_L}{\partial A}\right]+p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2}-\frac{\partial^2 x_L}{\partial A^2}\right]\left[\frac{dA^*}{d\theta}\right]\right\}=0, \tag{A.56}$$

which yields

$$\frac{dA^*}{d\theta}=\frac{p\left[\frac{\partial x_H}{\partial A}-\frac{\partial x_L}{\partial A}\right]}{p[1-\theta]\left[\frac{\partial^2 x_H}{\partial A^2}-\frac{\partial^2 x_L}{\partial A^2}\right]}<0, \tag{A.57}$$

since by (A.3), $\partial x_H/\partial A > \partial x_L/\partial A$ and $\partial^2 x_H/\partial A^2 - \partial^2 x_L/\partial A^2 < 0$. The result that $dR^*/d\theta > 0$ follows from the fact that $\partial R/\partial A = -1$. Thus, since $dA^*/d\theta < 0$, it follows that $dR^*/d\theta > 0$. ■

This proposition shows that as competition increases, the firm invests more in R&D and less in assets-in-place that are used to support and expand existing products. The economic intuition is that investing in coming up with proprietary new products/knowledge becomes more valuable *relative to* investing more in the existing business as competition compresses margins in existing products, but the output of R&D is patent-protected.

Since existing products have systematic risk, whereas R&D has only idiosyncratic risk, one implication of this result is that higher competition will lead to declining betas and increasing idiosyncratic risk for firms.[35] The volatility of payoffs associated with R&D is typically higher than that associated with well-established existing products, so we should expect an increase in the total volatility of stock returns as firms substitute investments in existing products with investments in R&D. Moreover, higher competition typically introduces greater uncertainty about a firm's prospects in any industry, leading to higher total stock return volatility. Because the higher investment in R&D is caused by higher competition, we have another channel through which R&D investments end up being positively correlated with total stock return volatility.

We can formally derive the conditions under which a shift in investment from assets-in-place to R&D increases the total volatility of the firm's returns. For this, define $S_x \equiv x_H - x_L$ as the "spread" between the low and high payoffs for the assets in place and $S_y \equiv y_+ - y_-$ as the "spread" for the payoffs of R&D conditional on first-stage success. Then $\partial S_x/\partial A > 0$ is the marginal impact of investment in assets-in-place on the spread S_x and $\partial S_y/\partial R > 0$ is the marginal impact of R&D investment on the spread S_y. Then we have the following result:

Corollary 1: *If S_y is sufficiently greater than S_x and $\partial S_y/\partial R$ is sufficiently greater than $\partial S_x/\partial A$, then the marginal impact of an increase in R&D investment accompanied by an equal decrease in investment in assets-in-place is to increase the variance of firm value.*

[35] As argued by Myers and Howe (1997), an increase in R&D may also generate an "R&D leverage" effect, which can increase systematic risk in a way similar to a financial leverage effect, by creating a series of fixed obligations (R&D investments) that must be paid in the future. In our analysis, the additional R&D investments are discretionary (i.e. the firm has no obligation to undertake them), and all the needed investment is raised up-front, so the effect is not applicable in our setting.

Proof: Available upon request. ■

Thus, if the spread between the payoffs conditional on success is much larger for R&D than for assets-in-place, and investment has a bigger marginal impact on this spread for R&D, we should expect higher R&D spending to induce an increase in total volatility. A large spread of payoffs conditional on success for R&D is consistent with the empirical evidence for pharmaceuticals of Grabowski and Vernon (1990), who document a skewed distribution of returns for drugs in the marketplace, with "blockbuster" drugs achieving much higher returns than other drugs.

We now examine how competition affects the firm's debt and cash positions.

Proposition 3: *An increase in competition will reduce the debt issued by the firm and increase the cash carried.*

Proof: As shown in Proposition 2, $\partial A^*/d\theta < 0$, so an increase in competition θ reduces the amount invested in assets-in-place. Since $F = x_L(A^*)$ and $\partial x_L/\partial A > 0$ from (A.3), it follows that a smaller A^* means a lower F, and hence less debt. In terms of the response of cash reserves to competition, Lemma 2 shows that the firm will prefer to raise all of the financing that it anticipates in the future at $t = 0$, and hold it as cash. The amount that the firm holds as cash for the future R&D investment is ωR. Therefore, since $\partial R^*/d\theta > 0$ from Proposition 2, an increase in competition θ increases the amount invested in R&D and hence the amount of cash that the firm holds at $t = 0$. ■

The intuition is that an increase in competition will induce the firm to reduce its investment in assets-in-place, which in turn reduces the amount of debt that the firm can carry since the face value is set to the lowest payout from the assets-in-place. Put differently, an increase in competition will reduce the collateral base of the firm that supports debt by reducing investment in assets-in-place. The firm holds additional cash in response to competition due to a precautionary demand for liquidity—it may not be able to raise enough financing in some states in the future. As the relative attractiveness of R&D goes up due to higher competition, so does the excess cash the firm carries to meet future liquidity demand. These two results also imply that net debt—defined as debt minus cash—will decline as competition increases.

A.5 Model Extension: An Acquisition as an Alternative to R&D

A realistic alternative that a biopharma firm has to investing in R&D in-house is to purchase another firm (such as a biotech firm) that has already successfully developed the R&D. To consider this possibility, suppose that the biopharma firm has the choice to acquire a biotech firm whose only asset is one R&D project that has successfully completed the first stage of R&D investment. For simplicity, consider the case in which the R&D is very successful. Thus, the biopharma firm, when it chooses to invest in R&D, may either invest in "internal" R&D by investing in the R&D

project described previously, or "external" R&D by acquiring the biotech firm. Acquisition occurs at $t = 0$, in which case the acquiring biopharma firm would identify a biotech firm that has successfully developed the R&D.

Let $\overline{V}_{external}$ be the value of the target (assumed to be unlevered, for simplicity) if it is not acquired:

$$\overline{V}_{external} = y_{+}\left(\overline{R}\right)[1-T]\,[1+r]^{-2}\,, \tag{A.58}$$

which is conditional on investment of $\overline{R}$ in the R&D, and y_{+} and $\overline{R}$ correspond to the target's expected R&D payoff and investment, respectively. We assume that the target does not have access to financing. If the target is purchased by the acquirer, then there is a synergy gain of $\triangle$, so the value of the target (the external R&D project) to the acquirer is:

$$V_{external} = \left[\triangle + y_{+}\left(\overline{R}\right)\right][1-T]\,[1+r]^{-2}\,. \tag{A.59}$$

The target may also have non-contractible benefits, B_t, from the R&D that are not reflected in (A.59) above and are not available to the acquirer. For simplicity, we assume that the target sells at a price that is exactly equal to $\overline{V}_{External}$, so that the target receives the expected value of what it would have received if it had the funds to invest in second-stage R&D, and the acquirer captures the entire synergy gain.[36]

When the good firm raises the financing it needs for its assets-in-place and to buy the target, insiders will value the total post-acquisition equity in the firm at:

$$\hat{V}_{E}^{i} = [1-T]\delta p[1-\theta]\,[x_H - x_L]\,[1+K]^{-2} + V_{external}, \tag{A.60}$$

whereas outsider shareholders will value it at $g\hat{V}_{E}^{i}$.

Let $\hat{A}$ be the investment in assets-in-place made by the acquiring firm. Then the share of ownership, $\hat{\alpha}$, that must be sold to outside shareholders to raise the necessary financing satisfies:

$$\hat{\alpha} g \hat{V}_{E}^{i} = \hat{A} + \overline{V}_{external} - \hat{D}, \tag{A.61}$$

where $\overline{V}_{external}$ is the price paid for the target and $\hat{D}$ is the debt level. As before,

$$\hat{D} = g\hat{F}\,[1+r]^{-2} + [1-g]\delta S[1+r]^{-1} = g x_L\left(\hat{A}\right)[1+r]^{-2} + [1-g]\delta S[1+r]^{-1}. \tag{A.62}$$

Whether the firm prefers to invest in internal R&D or external R&D (via acquiring another firm) depends on whether

$$\Omega \geq [1-\hat{\alpha}]\,\hat{V}_{E}^{i} \tag{A.63}$$

holds. If (A.63) holds, the firm will invest in internal R&D. If (A.63) does not hold, the firm will

[36] Alternative assumptions about the possible sharing of the synergy between the acquirer and the target do not affect our analysis qualitatively.

prefer to acquire.

Now, assume that there are two types of identifiably distinct acquirers: those with $q_+ + q_- \equiv q_1$ and those with $q_+ + q_- \equiv q_2$, with $q_1 < q_2$. Then we can prove the following result.

Proposition 4: *If the good firm with q_1 invests in internal R&D, so does the good firm with q_2. If the good firm with q_2 acquires another firm to obtain external R&D, so does the good firm with q_1. There are exogenous parameter values for which the good firm with q_1 acquires and the good firm with q_2 invests internally in R&D.*

Proof: Using (A.50), we can write Ω as

$$\begin{aligned}\Omega &= [1-T]\delta\left\{[1+r]^{-2}\left[q_+ y_+ + q_- y_-\right] + p[1-\theta]\left[x_H - x_L\right][1+K]^{-2} + [1-q_+-q_-]\,\omega R\right\} \\ &\quad +[1-T][1-\delta]\omega R - g^{-1}\left\{A + R[1+\omega] - [1-g]\delta S[1+r]^{-1}\right\} + F[1+r]^{-2} \\ &\quad +q_i B, \end{aligned} \tag{A.64}$$

where $q_i \equiv q_+^i + q_-^i$, $i \in \{1,2\}$. And:

$$\begin{aligned}[1-\hat{\alpha}]\,\hat{V}_E^i &= [1-T]\delta p[1-\theta]\left[x_H - x_L\right][1+K]^{-2} + V_{external} \\ &\quad -g^{-1}\left\{\hat{A} + \overline{V}_{external} - [1-g]\delta S[1+r]^{-1}\right\} + \hat{F}[1+r]^{-2}\end{aligned} \tag{A.65}$$

Note that $\partial\Omega/\partial q_i > 0$. The result now follows. ■

The basic idea is simple. A firm with a higher probability of success with internal R&D is more likely to invest in R&D, whereas a firm with a sufficiently low R&D success rate will prefer to engage in external R&D by acquiring a firm that has already successfully harvested the result of investing in R&D. Thus, acquiring firms will display lower R&D success rates than those that engage in organic R&D, all else being equal. This is a testable prediction.

Following from the analysis in the previous sections, it follows that an increase in competition will induce more firms to engage in external R&D via acquisitions. These will be the firms which have a lower probability of internal R&D success. Moreover, since external R&D involves less risk than internal R&D, one would expect acquiring firms' stock returns to have lower idiosyncratic risk than the stock returns of firms that engage in internal R&D. We leave tests of these predictions to future research.

Appendix B: Supplemental Empirical Results

Figure B1: Additional Competition Measures

These figures present additional estimates of sales-based competition over time for the biopharma industry. The top-left figure gives the 4-firm Concentration Ratio, calculated using equation (1). The top-right figure gives the value of the Herfindahl-Hirschman Index (HHI) over time, which is calculated as: $HHI_t = \sum_{i=1}^{N} s_{i,t}^2$, where s_i is the sales market share of firm i in year t. The bottom figures give the value of the Hannah-Kay Index over time, which is defined as: $HK_t(\alpha) = \sum_{i=1}^{N} s_{i,t}^{\alpha}$. A higher α represents a higher weight attached to larger firms in terms of sales. The bottom right figure gives results for $\alpha = 1.5$ (relatively more weight to smaller firms in terms of sales), while the bottom right figure gives results for $\alpha = 2.5$ (relatively more weight to larger firms in terms of sales). For all measures, a higher value indicates more concentration (i.e. less competition).

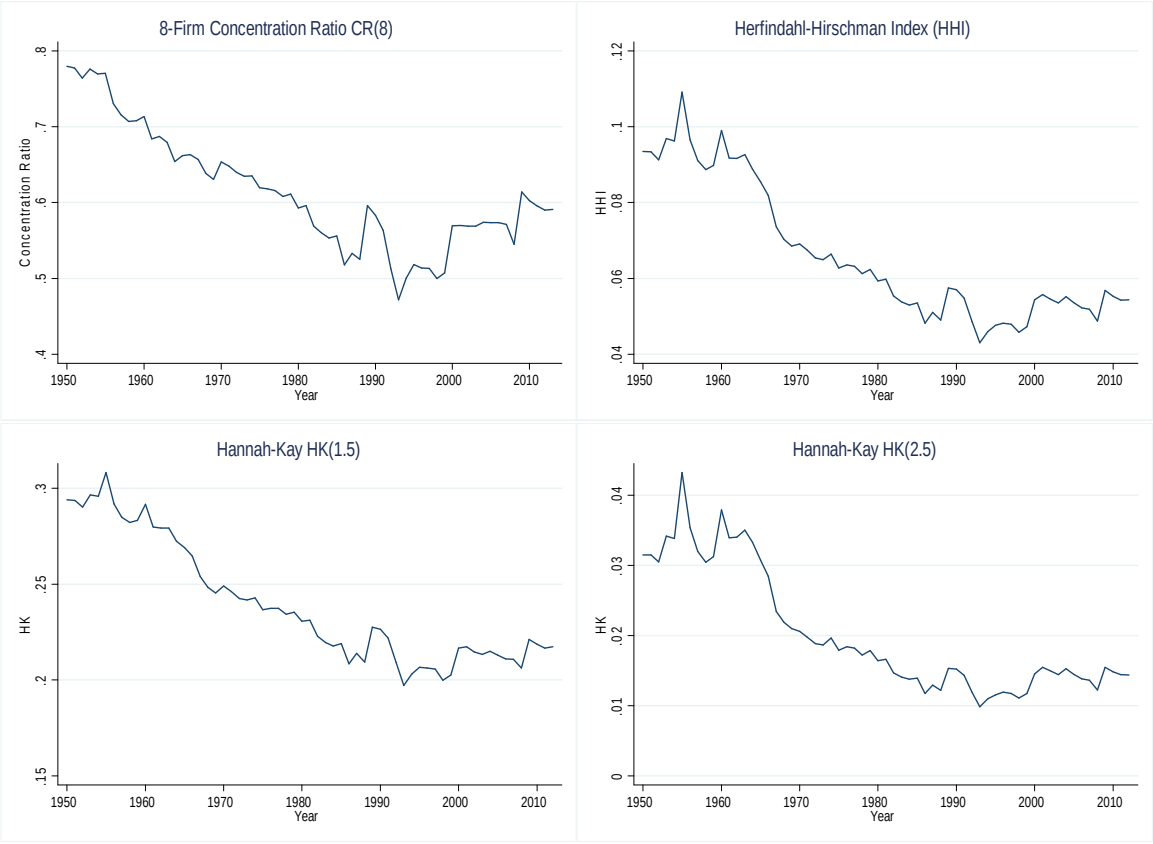
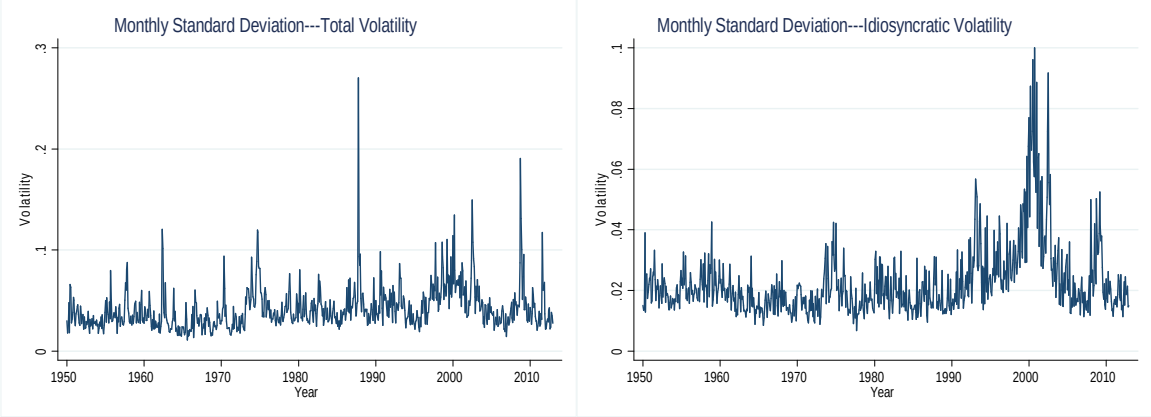


Figure B2: Total and Idiosyncratic Stock Return Volatility

This figure shows the monthly estimates of value-weighted portfolio volatility, following Schwert (1989). In panel (a), the left graph depicts total stock return volatility, calculated by forming a value-weighted portfolio of biopharma stocks, and then estimate the monthly standard deviation of the total portfolio as the square root of the sum of the squared daily excess (over the mean daily return in the month) returns over the month: $\hat{\sigma}_{P,T} = \sqrt{\sum_{t=1}^{D_T} (R_{P,t} - \mu_T)^2}$, where $R_{P,t}$ is the daily portfolio return for date t and μ_T is the mean daily portfolio return for month T. In a similar way, the right graph in panel (a) depicts idiosyncratic volatility, which is given by: $\hat{\sigma}_{P,T}^{idio} = \sqrt{\sum_{t=1}^{D_T} \left(\epsilon_{P,t} - \mu_T^{idio}\right)^2}$, where $\epsilon_{P,t}$ is the idiosyncratic return of the value-weighted portfolio for day t and μ_T^{idio} is the mean idiosyncratic return in month T. Augmented Dickey-Fuller tests were also run on these monthly series to test for the presence of a unit root. For both total volatility and idiosyncratic volatility, Augmented Dickey-Fuller tests reject the presence of a unit root at at least the 5% level when up to 5 lags are included, regardless of whether a trend is included.

(a) Levels of $\hat{\sigma}_{P,T}$ and $\hat{\sigma}_{P,T}^{idio}$



(b) Moving Average of $\hat{\sigma}_{P,T}$ and $\hat{\sigma}_{P,T}^{idio}$

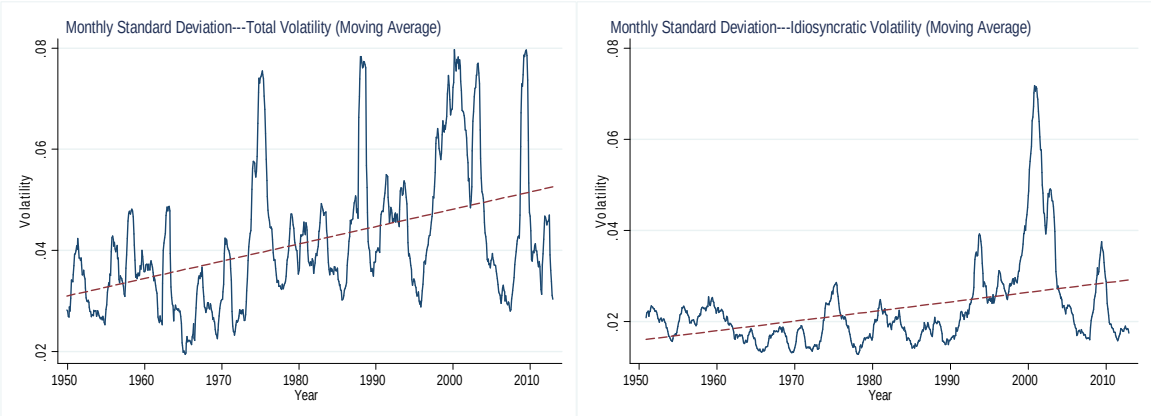
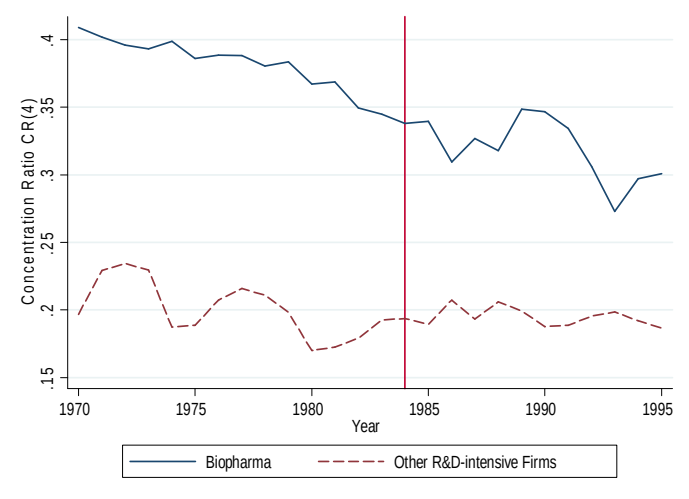


Figure B3: Changes in Competition Around Hatch-Waxman Act

Panel (a) depicts the 4-firm Concentration Ratio CR(4) for the biopharma industry (the solid blue line) and the propensity-score matched sample of other R&D-intensive firms (the dashed red line) around the enactment of the Hatch-Waxman Act. Panel (b) estimates a differences-in-differences regression for the effect of the Hatch-Waxman Act on the Concentration Ratio CR(4) of the biopharma industry versus other R&D-intensive firms. The regression is run at the industry-year level. $CR_{i,t}(4)$ is the value of the 4-firm concentration ratio for group i, either the biopharma industry or other R&D-intensive industries. HW_t is a dummy variable which takes a value of 1 if the year is 1984 or later, and a value of zero otherwise. $Biopharma_i$ is a dummy variable which takes a value of 1 for the biopharma industry, and a value of 0 otherwise. Robust standard errors are given in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

(a) Competition Trends for Biopharma and Control Group



(b) Differences-in-Differences Estimation for Changes in Competition

Dependent Variable:	$CR_{i,t}(4)$
$Biopharma_i \times HW_t$	-0.057^{***}
	(0.010)
$Biopharma_i$	0.182^{***}
	(0.008)
HW_t	-0.006
	(0.006)
Constant	0.201^{***}
	(0.006)
Observations	42
R^2	0.953

Figure B4: Risk Variable Trends for Treatment and Control Group

Trends for risk variables. Beta variables are yearly estimates, calculated from a value-weighted portfolio of biopharma or propensity-score matched R&D-intensive firms using the previous 2 years of daily portfolio returns as of the end of each year. Volatility variables are yearly estimates, calculated using the daily returns over the year of a value-weighted portfolio of biopharma or control firms. The solid blue lines give estimates for the biopharma industry, while the red dashed lines give estimates for the propensity-score-matched sample of R&D-intensive firms. A vertical red line is included in each graph, representing the year that the Hatch-Waxman Act was implemented.

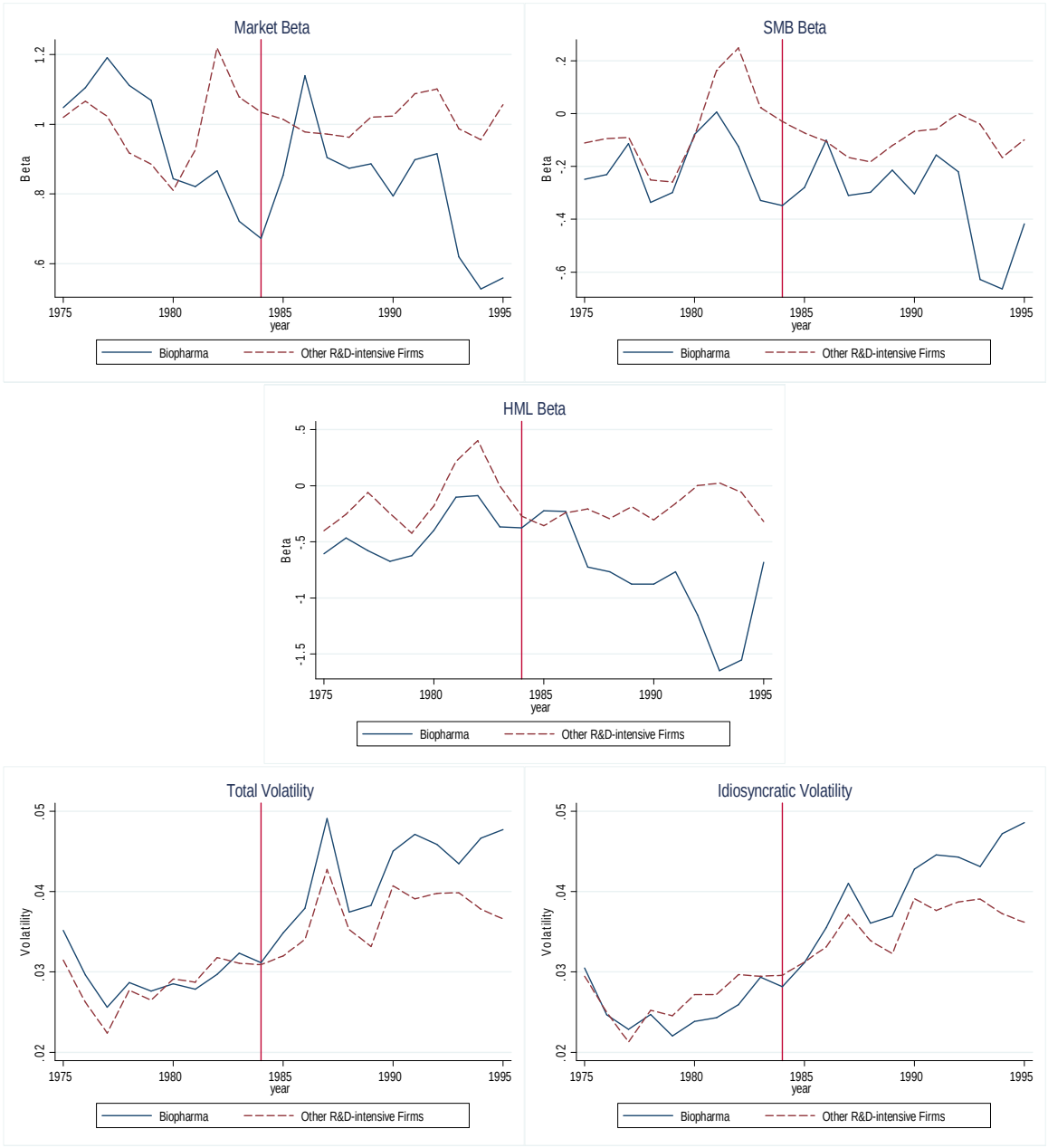


Table B1: Time-series Regressions

Time-series regressions of the effect of competition on levels of financial characteristics. Each entry in the table is a univariate regression of the effect of the indicated measure of competition on the indicated financial characteristics for the biopharma industry. All variables are yearly estimates, yielding 63 observations per regression. For the competition measures, Number Competitors is the number of firms in the biopharma industry each year, $CR(M)$ is the M-firm Concentration Ratio, HHI is the Herfindahl-Hirschman Index, and $HK(\alpha)$ is the Hannah-Kay Index with weight α. An increase in the concentration index measures indicates a decrease in competition. $R\&D$, PPE, $Cash$, $Debt$, and $Net\,Debt$ are median estimates, calculated by first scaling each variable by total assets at the firm-year level, and then taking the median across all firms (other than debt, which has a skewed distribution as previously explained, results are robust to using mean levels of these variables). σ is mean total stock return volatility, while σ^{idio} is mean idiosyncratic stock return volatility, each calculated by taking the standard deviation of the past 360 days of daily total or idiosyncratic returns as of the last day of each year for each firm, and then averaging across all firms. $\beta_{mkt,t}$, $\beta_{SMB,t}$, and $\beta_{HML,t}$ are betas of a value weighted portfolio of biopharma firms, calculated using (2) for the past 2 years of daily returns as of the last day of each year. Autocorrelation-adjusted (for up to 5 lags) standard errors are in parentheses, calculated following Newey and West (1987), while R-squared estimates are given in brackets. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Independent	Dependent Variable									
Variable	R&D	Cash	PPE	Debt	Net Debt	σ	σ^{idio}	β_{mkt}	β_{SMB}	β_{HML}
Number	0.0003***	0.0007***	−0.0004***	−0.0001	−0.0005***	0.00005***	0.00005***	−0.0005***	−0.0006***	−0.0004*
Competitors	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0002)	(0.0002)
	[0.895]	[0.906]	[0.962]	[0.075]	[0.620]	[0.694]	[0.716]	[0.473]	[0.365]	[0.105]
$CR(4)$	−0.828***	−1.479***	1.011***	−0.271	0.803*	−0.170***	−0.167***	1.895***	3.285***	3.212***
	(0.198)	(0.376)	(0.173)	(0.165)	(0.432)	(0.021)	(0.021)	(0.325)	(0.600)	(0.761)
	[0.393]	[0.311]	[0.513]	[0.075]	[0.100]	[0.585]	[0.606]	[0.478]	[0.663]	[0.408]
$CR(8)$	−0.658***	−1.144***	0.774***	−0.191	0.666*	−0.137***	−0.134***	1.454***	2.551***	2.573***
	(0.153)	(0.330)	(0.148)	(0.137)	(0.391)	(0.021)	(0.021)	(0.330)	(0.641)	(0.696)
	[0.351]	[0.265]	[0.428]	[0.053]	[0.100]	[0.537]	[0.558]	[0.400]	[0.569]	[0.372]
HHI	−2.983***	−5.369***	3.805***	−1.207**	2.602	−0.625***	−0.612***	7.087***	12.165***	11.176***
	(0.779)	(1.555)	(0.684)	(0.568)	(1.689)	(0.088)	(0.087)	(1.175)	(2.231)	(2.599)
	[0.374]	[0.300]	[0.532]	[0.110]	[0.076]	[0.577]	[0.595]	[0.490]	[0.666]	[0.362]
$HK(1.5)$	−1.824***	−3.307***	2.257***	−0.545	1.798*	−0.364***	−0.356***	4.049***	6.743***	6.110***
	(0.436)	(0.929)	(0.403)	(0.343)	(1.010)	(0.049)	(0.049)	(0.695)	(1.390)	(1.507)
	[0.442]	[0.360]	[0.592]	[0.071]	[0.115]	[0.618]	[0.637]	[0.502]	[0.646]	[0.342]
$HK(2.5)$	−5.740***	−10.359***	7.533***	−2.775**	4.550	−1.242***	−1.217***	14.378***	24.994***	22.869***
	(1.614)	(3.114)	(1.383)	(1.105)	(3.346)	(0.186)	(0.184)	(2.263)	(4.047)	(5.152)
	[0.331]	[0.267]	[0.498]	[0.138]	[0.056]	[0.545]	[0.562]	[0.481]	[0.671]	[0.362]