How Do Financing Constraints Affect Firms' Equity Volatility?*

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Abstract

Higher firm equity volatility is often associated with non-fundamental trading by investors or constraints on firms' ability to insulate their value from economic risks. This paper provides evidence that an important determinant of higher equity volatility among R&D-intensive firms is fewer financing constraints on firms' ability to access growth options. I provide evidence for this effect by studying how persistent shocks to the value of firms' tangible assets (real estate) affect their subsequent equity volatility. The analysis addresses concerns about the identification of these balance sheet effects and shows that these effects are consistent with broader patterns on the equity volatility of R&D-intensive firms.

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Firms experience substantial volatility in their equity value. Though most firm equity volatility is idiosyncratic, it matters for several reasons. For example, idiosyncratic volatility is important for determining portfolio allocations (Campbell et al. (2001)) and for the large number of investors that are imperfectly diversified (Campbell (2006)). It can also directly affect firm value in the presence of frictions, such as financing constraints, and plays a central role in a large literature studying corporate risk management policies.[1] It also matters for large shareholders who might play an important corporate governance role (Shleifer and Vishny (1986)), managers who typically hold equity stakes due to compensation policies, and because it limits firms' ability to provide incentives through these policies.[2] Additionally, arbitrageurs who trade to exploit the mispricing of individual stocks face risks that are related to idiosyncratic return volatility. Therefore, larger pricing errors are possible when equity volatility is higher (Shleifer and Vishny (1997)). Finally, equity volatility plays an important role in the pricing of derivatives such as options on a given stock.

While previous research suggests that firms' cash flow fundamentals might play a significant role in explaining their equity volatility, we still have a limited understanding of the underlying economic factors determining the level of firms' equity volatility.[3] Understanding this link is important because, in its absence, higher firm equity volatility is often viewed as capturing non-

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[1] For example, see Froot, Scharfstein, and Stein (1990); Opler et al. (1999); Almeida, Campello, and Weisbach (2004); and Bates, Kahle, and Stulz (2009).

[2] Even in the United States, large shareholders are important in most publicly traded firms (e.g., Amit and Villalonga (2009)). Panousi and Papanikolaou (2012) also provide evidence that ownership by insider managers is significant for a large subset of firms, especially small firms with high idiosyncratic volatility. Previous research has suggested, both theoretically and empirically, that greater firm-specific risks lead to weaker incentive contracts for managers and leads them to lower firm investment (e.g., Aggarwal and Samwick (1999); Lin (2002); and Panousi and Papanikolaou (2012)).

[3] Variation in equity volatility across both firms and time is positively correlated with higher cash flow volatility (e.g., Pastor and Veronesi (2003); Comin and Philippon (2005); and Irvine and Pontiff (2009)). Moreover, decompositions of firm-level stock price fluctuations suggest that news about expected cash flows plays an important role in driving them (Vuolteenaho (2002)).

fundamental trading, such as noise trading or speculation, and motivates policies addressing it.[4] Moreover, different interpretations for the underlying economic risks driving higher levels of firm equity volatility can lead to different implications.

This paper studies the role of financing constraints in determining firms' equity volatility. I argue that higher equity volatility can be a product of fewer financing constraints on firms' ability to take advantage of growth options. When capital markets are imperfect, the availability of financial resources is a natural factor determining firms' ability to access growth options. If uncertainty about future growth opportunities is an important source of risk for firms, and future investment opportunities can become highly valuable relative to current opportunities, then the following growth-options channel can become important. As financing constraints are relaxed, firms decide to largely preserve their increased access to liquidity to fund future potential growth opportunities, as opposed to finance their current investment. Consequently, firms are mostly affected through an increase in the value of unexercised growth options, and this leads to higher equity volatility. Given that R&D investments represent a major source of growth options, this growth-options channel is arguably most important for R&D-intensive firms. This channel suggests that higher levels of equity volatility among small and young firms, particularly R&D-intensive and innovative firms, might capture reductions in frictions usually associated with higher firm value and economic growth.[5]

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[4] For example, see Stiglitz (1989); Summers and Summers (1989); Schwert and Seguin (1993); Davila (2014); and the references therein for discussions of policies addressing higher stock return volatility caused by non-fundamental trading. Previous research has provided evidence suggesting that non-fundamental trading such as noise trading or speculation by retail investors can be important in explaining firm stock return volatility (e.g., Brandt et al. (2010) and Focault, Sraer, and Thesmar (2011)).

[5] According to this view, financing constraints cannot explain the greater volatility of small and young firms, which might be explained instead by their greater economic exposure to growth options. However, financing constraints can explain why such firms might have higher volatility in environments with fewer financing frictions limiting small and young firm growth. For example, Bartram, Brown, and Stulz (2012) provide evidence that U.S. firms have significantly higher equity volatility than similar firms in other countries.

The implications of financing frictions for firm equity volatility can be significantly different if these frictions mostly matter by shaping firms' exposure to liquidity risks. Previous research argues that financing frictions lead to undesirable fluctuations in firms' liquidity positions that can affect decisions such as firm investment (Froot, Scharfstein, and Stein (1990); Holmstrom and Tirole (1998); and Opler et al. (1999)). According to this literature, such liquidity risks reduce firm value and create a motive for financially constrained firms to attempt to reduce fluctuations in their value through risk management policies. Since firms might be limited in their ability to reduce their exposure to liquidity risks, a natural possibility suggested by these ideas is that higher financing constraints leads to increases in firms' equity volatility as a consequence of such increased risks. Therefore, higher levels of equity volatility among small and young firms might be explained by greater financing constraints and liquidity risks, which might significantly reduce firms' value and impose costs on their investors.[6]

Two main challenges arise in addressing the importance of these effects. First, it is necessary to identify some significant source of variation across firms in the importance of financing frictions. Second, it is necessary to empirically disentangle variation in the importance of these frictions from variation in the underlying economic conditions faced by firms. This paper addresses these challenges by examining the impact of persistent shocks to the value of firms' real estate holdings. A large literature emphasizes how increases in the value of firms' tangible assets can relax financing constraints and that shocks to the value of firms' real estate holdings are an important and frequent source of shocks to the balance sheets of many firms.[7] While

[6] An important issue is that relaxed financing constraints will lead to endogenous changes in firms' financial policies (e.g., higher leverage) that can also affect the volatility of firm value. This issue is addressed in the empirical analysis.
[7] For example, see Hart (1995) and the references therein. Gan (2007) and Chaney, Sraer, and Thesmar (2012) provide evidence that increases in the value of firms' real estate holdings lead to increases in their borrowing

R&D-intensive firms rely less on tangible assets, a significant fraction of R&D-intensive firms are potentially exposed to this source of variation in financing constraints. As a first step in the analysis, I illustrate the theoretical possibilities previously discussed in the context of a framework where firms make investment decisions subject to collateral constraints, and increases in the value of tangible assets relax financing constraints.

Instrumented shocks to local real estate prices are then constructed by using differences across U.S. regions in the geographically determined availability of land, which leads different regions to have different exposures to national real estate cycles. I estimate the effect of shocks to the value of firms' real estate holdings by combining these local real estate shocks with pre-existing differences across firms in their exposure to real estate in their balance sheet.

Based on this approach, I find that increases in the value of firms' real estate holdings lead to significant increases in the subsequent volatility of their stock returns. Moreover, the results suggest that this effect is driven by the previously described growth-options channel. These shocks to firms' balance sheets are associated with immediate increases in firms' equity volatility. These persistent shocks are also associated with increases in investment and debt issuance by firms, which are arguably limited when compared to the changes in the value of real estate holdings. These effects are also matched with drops in firm market leverage or net market leverage and are not associated with higher subsequent cash flow volatility. Moreover, these effects are driven by increases in the idiosyncratic volatility of R&D-intensive firms. I find that these shocks are associated with no important changes on the equity volatility of firms less likely to rely on growth options such as firms that do not intensively rely on R&D as well as mature

capacity and real investment. Benmelech and Bergman (2009) provide evidence that higher collateral values reduce borrowing costs.

and large firms.[8] Based on these results, I find that relaxed financing constraints can be an important determinant of higher firm equity volatility in broad samples of R&D-intensive firms which hold some real estate assets. The results imply that typical shocks to real estate prices increase firm equity volatility between 27-30% of one standard deviation in equity volatility changes in these samples.[9]

An important concern with the previous results is that local real estate shocks might not only affect local firms through their balance sheets. As local economic conditions change in response to real estate shocks, the fundamentals of local firms could be affected by other channels that also matter for their volatility. This issue will only matter for the analysis if these alternative channels differentially affect firms which own more real estate prior to real estate shocks. However, firms' initial ownership of real estate assets could be related to unobserved firm characteristics that also predict their exposure to these alternative channels. While completely ruling out this possibility is challenging, I address this concern with several tests that contrast the predictions from the previous balance sheet effects with the ones from alternative channels. For example, I provide evidence suggesting that changes in aggregate local demand conditions cannot explain the results. I also provide evidence that a range of observable firm characteristics correlated with real estate ownership do not drive the results through alternative channels.

I then examine the external validity of these results by studying changes in the equity volatility of R&D-intensive firms during the recent financial crisis, a period where financing

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[8] As discussed in greater detail in Section 3, these results all match the specific predictions from the growth-options channel. As soon as constraints are relaxed, firms have greater access to options and their volatility should increase. As firms decide to keep some of these options, as opposed to exercise them immediately, their debt does not increase as much as the market value of their assets and their market leverage drops. In contrast, because of adjustment costs, relaxed frictions are unlikely to have a significant immediate effect on the composition of firms' existing projects, as well as their operating and financing structure.

[9] The goal of the analysis is to examine the role of financing constraints and real estate shocks will only significantly affect the financing constraints of a subset of firms that hold real estate assets. While analyzing firms exposed to these real estate effects, I consider broad subsamples of R&D-intensive firms.

constraints are arguably more important. I document that the equity volatility of R&D-intensive firms differentially drops to historically low values during the crisis. I provide evidence that the significance of this drop across firms with different financial positions prior to the crisis is consistent with the idea that financing constraints drive this important pattern in equity volatility.

This paper contributes to a growing literature studying firms' equity volatility. The first contribution of this paper is to provide evidence that an economically important determinant of higher levels of equity volatility among R&D-intensive firms is reduced financing constraints. The second contribution of this paper is to provide evidence that this effect captures firms' greater financial ability to access growth options. A large body of previous research has focused on documenting and analyzing the time-series behavior of aggregate idiosyncratic volatility.[10] The important empirical facts documented in this literature led to an active debate about their interpretation and the role of different underlying determinants of idiosyncratic volatility. The evidence in this paper complements these analyses by isolating the importance of one underlying determinant of firms' equity volatility and its role in explaining differences in equity volatility across different types of firms and economic environments.

This focus on the underlying determinants of differences in equity volatility across firms is similar to the one of Bartram, Brown, and Stulz (2012, hereafter BBS), which analyzes the importance of different economic factors in determining the higher idiosyncratic volatility of U.S. stocks relative to matched foreign stocks. Consistent with the broad conclusions of BBS, the

[10] For example, see Campbell et al. (2001); Bennett, Sias, and Starks (2003); Wei and Zhang (2006); Brown and Kapadia (2007); Cao, Simin, and Zao (2008); Irvine and Pontiff (2008); Brandt et al. (2010); and Bekaert, Hodrik, and Zhang (2012). This focus on idiosyncratic volatility contrasts with studies of the time-series behavior of market volatility (e.g., French, Schwert, and Stambaugh (1987) and Schwert (2002)). A smaller related literature analyzes important firm-level patterns in equity volatility (e.g., Duffee (1995) and Grullon, Lyandres, and Zhdanov (2012)). As in these studies, this paper uses daily data to analyze the behavior of historical volatility without imposing any parametric model that describes the evolution of variance over time.

results in this paper suggest that conditions allowing firms to better take advantage of growth options play an economically important role in determining higher levels of volatility for U.S. stocks. The evidence in this paper complements their analysis by isolating the role of reduced financing constraints in determining higher levels of equity volatility among U.S. firms, conditional on the importance of other factors also affecting firms' equity volatility. While BBS include measures of country-level differences in financial markets in their analysis, they find mixed evidence across these measures and it is difficult to isolate the role of financing frictions from other cross-country characteristics potentially correlated with such measures in cross-country comparisons.[11] The results in this paper also complement the analysis in BBS by providing evidence on the mechanism through which financing constraints affect firms' equity volatility and by showing that this effect is concentrated among R&D-intensive firms.

Additionally, these findings relate to previous research examining the asset pricing implications of financing constraints. This research is motivated by the idea that financing constraints should increase firms' systematic risks because of liquidity shocks.[12] While this research typically focuses on cross-sectional patterns in stock returns, Lin and Paravisini (2013) provide evidence that adverse shocks to banks' balance sheets increase the systematic risk of borrowing firms.[13] The results in this paper complement this research by illustrating that relaxed

[11] In other words, in the presence of omitted country-level variables and measurement error in country-level control variables, it is difficult to attribute cross-country differences in equity volatility across firms to any specific country characteristic such as financial development.
[12] For example, see Lamont, Polk, and Saa-Requejo (2001); Whited and Wu (2006); Livdan, Sapriza, and Zhang (2009); and Li (2011).
[13] Lin and Paravisini (2013) do not examine changes in firm equity volatility. They analyze changes in measures of firm cash-flow volatility across subsequent quarters. However, the analysis in this paper illustrates both empirically and theoretically that the growth-options effects here emphasized should not be captured by these cash-flow volatility measures. Shocks to the balance sheets of banks might affect the risk of borrowing firms through effects on both bank and firm decisions. In contrast, the analysis in this paper examines the effects of shocks to firms' balance sheets and studies the implications of firms' financing constraints.

financing constraints can have an effect on firms' idiosyncratic risks of the opposite sign than predicted by the previous idea based on liquidity shocks. The analysis in this paper suggests that a natural reason for this gap is the contrast between the implications of financing constraints for growth opportunity risks and liquidity risks. Uncertainty about future growth opportunities is arguably a more important driver of firm idiosyncratic risks than a driver of systematic risks.

Finally, these findings have potential implications for a large literature on the value and determinants of risk-management policies. As previously discussed, theory suggests financing constraints expose firms to liquidity risks and create a motive for risk management. In practice, hedging tends to be concentrated among large and mature firms, which are likely to be less financially constrained. Previous research has often pointed this issue as a puzzle and debated over its possible explanations (e.g., Rampini and Viswanathan (2010)). At least in the context of R&D-intensive firms, the results in this paper provide a rationale for why small and young firms might not want to hedge a significant portion of the risks affecting their value. Namely, because of growth opportunity risks, firms might value marginal increases in liquidity more in high-value states of the world than in low-value states of the world.[14]

1. Theoretical Framework

This section illustrates the previous intuitions for how financing constraints affect firms' equity volatility in simple terms with a model of investment with financing frictions. The model is motivated by the specific features of the empirical analysis. I discuss the key intuitions for the results in this section and present the formal analysis in Appendix A.

[14] Froot, Scharfstein, and Stein (1990) emphasize the point that financially constrained firms should not hedge fluctuations in their value driven by changes in investment opportunities, and Babenko and Tserlukevich (2013) argue that this could be a reason why hedging is concentrated among large and mature companies without many growth options.

The model is a partial equilibrium model where firms live for three periods and can only raise external funds by borrowing subject to collateral constraints. Firms face a sequence of projects (investment opportunities) and the capital invested in a specific project is illiquid, i.e., firms can only liquidate it at a significant loss prior to the last period. Firms' borrowing capacity is determined by the value of their tangible assets. In the first period, firms are endowed with capital in an ongoing project and have the option to continue investing in that project and borrow. Uncertainty is resolved (there are two states) after these decisions are made. In the second period, firms have the option to invest in a new project only if the good state is realized. If the bad state is realized, they might experience temporary losses from the initial project. Finally, in the third period, cash flows from both projects are realized and firms pay dividends. I consider how a persistent increase in the price of tangible assets at the beginning of the first period affects firms' subsequent equity volatility. For expositional simplicity, the model abstracts from effects of the price of capital in firms' cost of using capital by normalizing the interest rate to zero. In the empirical analysis that follows, I explicitly address this possibility. Therefore, in the model, a change in the price of tangible assets is equivalent to a change in firms' net worth and only relaxes financing constraints.[15]

When financing constraints are relaxed, firms face the following trade-off. On the one hand, they have the option to use their increased access to finance to invest in the initial project in the first period. As firms invest in the project, they convert liquid funds into illiquid assets. This reduces the availability of liquidity in the second period. Alternatively, firms can preserve their increased access to finance to manage their liquidity in the second period. More liquidity in the good state allows firms to respond more to investment opportunities in the second period. In the

[15] The effects here analyzed are different from the one analyzed by Almeida and Campello (2007).The effects here examine the impact of firms' initial net worth as opposed to the effect of their asset tangibility.

bad state, more liquid funds reduce liquidity costs in the second period. In other words, firms need to decide between converting their increased liquidity right away into illiquid assets and preserving it to better respond to future growth opportunities or future liquidity risks.

In the simplest version of the model, firms can manage their liquidity in the second period only by preserving their debt capacity. By borrowing and investing less in the first period, firms have greater ability to borrow and access liquid funds in the second period. However, I show that the central results of the model are robust to allowing firms to manage their risks with other tools, also subject to collateral constraints. For example, firms can manage their liquidity in the second period with cash holdings, lines of credit, or hedging contracts.

Two important conditions lead to the growth-options channel in this framework. First, most risks faced by the firm in the second period are risks about their investment opportunities, as opposed to liquidity conditions. Second, the value of investing in the new project is high when compared to the value of investing in the initial project. Under these conditions, firms decide to preserve their increased liquidity to potentially invest more in the growth opportunity in the second period. As a consequence, an initial relaxation of financing constraints affects firms mostly by making their future investment more responsive to future growth opportunities.

As relaxed financing constraints increase the upside from future growth opportunities, they lead to increases in the subsequent equity volatility of firms. Rational investors price these potential upsides when determining initial stock prices. As news about investment opportunities are revealed over time, investors' expectations and stock prices fluctuate. When firms can respond more to growth opportunities, news on these opportunities matter more for firm value and stock price volatility is higher. One way to interpret this result is to note that relaxed financing constraints mostly increase firm value in future good states. The increased dispersion in future valuations between good and bad states leads to higher future stock price volatility. Another way to interpret this result is to note that relaxed financing constraints affect firms mostly by providing them with more unexercised growth options which increase the risks in predicting future firm value. Notice that firms do not want to initially hedge this volatility in their value. Instead, they prefer to increase their exposure to this volatility by responding more to future growth opportunities but are financially constrained.

When firms mostly face risks about liquidity conditions, relaxed financing constraints can reduce the subsequent volatility of stock returns. If the value of the initial project is limited, firms might use relaxed financing constraints to mitigate liquidity costs in the second period. In this case, the main effect of relaxed financing constraints will be to reduce future losses in response to liquidity shocks. This will mostly increase firm value in future bad states and reduce the dispersion of future valuations across different states. As news about liquidity conditions are revealed over time, investors' expectations and stock prices fluctuate less.

In this framework, relaxed financing constraints can also increase the subsequent volatility of firm stock returns through a liquidity channel. Imagine again that liquidity risks are important but suppose now that expanding the initial project is more profitable. In this scenario, the firm might use its increased access to liquid funds to invest more in the initial project. While this strategy is optimal for firms, it can lead them to engage in more asset liquidations and experience greater value losses in the bad state. Firms' value becomes more volatile because they endogenously choose a more fragile liquidity position.

The previous analysis of the growth-options channel assumes that firms mostly face risks about investment opportunities. An interesting possibility outside the model is that liquidity risks are equally important, but firms are initially less constrained in their ability to respond to liquidity shocks. For example, firms might find it especially difficult to increase their liquidity in states of the world where innovations or new ideas take place. Consequently, marginal changes in financing constraints might have a limited impact in reducing liquidity risks and mostly matter through the growth-options channel.

Additionally, one can imagine the growth-options channel in a similar model with more periods where both investment and equity volatility increase over multiple periods. After constraints are relaxed, investment increases because some of the additional real options available are exercised in each period. At the same time, firms decide to keep a significant portion of these new real options unexercised and this leads the increase in equity volatility to be persistent. In this scenario, the increase in future investment is limited when compared to the increase in firms' borrowing capacity.[16] Finally, firms are indifferent between different options to preserve their increased liquidity in the model. However, considerations outside the model suggest that firms might prefer to preserve their debt capacity as a strategy to finance future growth opportunities. For example, firms might prefer to save debt capacity than to hold cash in this context if their debt has a significant risk of default.[17] This would lead the increase in firm equity volatility to be associated with an increase in firms' unused debt capacity.

[16] In the model in Appendix A, there are no decreasing returns to investing in projects and the growth-options channel is associated with an increase in investment only in the second period. However, the key condition for the growth-options channel is that relaxed financing constraints mainly provide firms with additional unexercised growth options. This will happen as long as the investment effect in the first period is limited.
[17] For example, see Acharya, Almeida, and Campello (2007).

2. Data, Variable Construction, and Summary Statistics

I describe the databases used in the two empirical analyses in the paper. In both cases, I start with data from COMPUSTAT's North America Fundamentals Annual, Quarterly, and CRSP. Following standard practice in the literature, I exclude financial firms (SIC codes 6000 to 6999) and regulated utilities (SIC codes 4900 to 4999).

2.1. Balance Sheet Shocks Analysis

For inclusion in the initial database in a given year, firms must have COMPUSTAT and CRSP data in both the current year and five years in the past. Firms must also have headquarters located in the U.S. as well as non-missing industry SIC codes and headquarter zip codes in both these years. Finally, in the initial database, I only keep firms with non-missing values of *Size*, *Cash Flow,* and *Age*. These last variables are defined based on five-year lags in Appendix B.

The analysis requires measuring changes in the value of firms' real estate holdings over time. The magnitude of changes in the value of real estate holdings is measured as a percentage of firms' assets. Following Nelson, Potter, and Wilde (1999), three categories of property, plant, and equipment are included in the definition of real estate assets: Buildings, Land and Improvement, and Construction in Progress. I use the book value of assets from COMPUSTAT to compute these ratios. While these assets are valued at historical cost, I focus on ratios of the values of different types of assets. The results use 5-year periods. *RERatio* is the five-year lag of the ratio of real estate assets (*ppenb* + *ppenli* + *ppenc*) to total assets (*at*). The breakdown of firms' real estate assets is not available in COMPUSTAT after 1993. For years after 1998, the value of these variables is defined using the ratio in 1993. *ΔREHoldings* is the product of *RERatio* and a measure of the price growth of firms' real estate assets between years *t* and *t-5.*

This product captures the change in the value of firms' real estate assets between years *t* and *t-5*, as a percentage of firms' assets at year *t-5*.

An important challenge in this analysis is identifying the location of firms' real estate assets. COMPUSTAT does not identify the location of each of firms' real estate assets. As in previous research (e.g., Chaney, Sraer, and Thesmar (2012)), I use the location of firms' headquarters (MSA) as a proxy for the location of firms' real estate. I then capture changes in the value of firms' real estate properties by looking at percentage changes in real estate price indexes for these areas. One concern with this approach is that one is approximating the location of firms' real estate assets by their MSA. Note that if a significant portion of firms' real estate holdings are outside these areas, one will overestimate changes in the value of these holdings and, as a consequence, underestimate the impact of changes in the value of firms' real estate holdings. In the Internet Appendix, I examine the importance of this issue by also measuring the location of firms' real estate assets at the state level and comparing results across these cases.[18]

In the main results, I use data on residential estate prices to compute the price growth of real estate holdings. Residential real estate data comes from the Office of Federal Housing Enterprise Oversight. The O.F.H.E. computes the Housing Price Index (HPI), which is based on transactions involving mortgages on single-family properties purchased or securitized by Fannie Mae or Freddie Mac. The HPI is a repeat-sales index, meaning that it measures average price changes in repeat sales or refinancings on the same properties. I use the HPI in the main results, as opposed to commercial real estate indexes, for the following reasons. It has significantly greater coverage across properties, regions, and time. Additionally, while the HPI is based on

[18] Also notice that this issue is likely to be less important for smaller firms, which are also the most likely to be affected by stronger balance sheets.

market prices, available commercial real estate indexes are based on appraisals, which are less accurate measures of market valuations. In the Internet Appendix, I address the concern that residential prices are likely to be a noisy proxy for commercial prices by also estimating results with commercial real estate price indexes. In the empirical analysis that follows, I also show that the instrumented shocks to local real estate prices used in the paper capture significant changes in both local residential and commercial real estate prices. This is consistent with previous research suggesting the importance of the link between these two markets (Gyourko (2009)).

The instruments for shocks to local real estate prices use measures of the geographically determined availability of land from Saiz (2010). Saiz (2010) uses satellite-generated data on terrain elevation and presence of water bodies to estimate the amount of undevelopable land in U.S. metropolitan areas. Land can be classified as unavailable for different reasons, and I use this information while constructing instruments. Variables *Uland_1* to *Uland_5* capture shares of land unavailable as a consequence of different geographic features of regions and are defined in Appendix B.[19]

The final sample is obtained by restricting the initial database described above further to observations with non-missing values of *ΔREHoldings* and the land availability variables. The first restriction requires firms to be present in the data in 1993 or earlier.

I construct measures of equity volatility using daily returns over 250 trading days. These measures capture annualized standard deviations of daily stock returns over fiscal years; their construction is described in greater detail in Appendix B. Given a fixed value for firms' asset

[19] Unavailable land is computed as a share of a 50km radius of each metropolitan central city that is unavailable because of the city's geography. For example, land might be unavailable because of high slopes or the presence of oceans. These variables are available for 269 MSAs.

volatility, their equity volatility will mechanically change with changes in leverage. I compute measures of unlevered equity volatility using the following expression:

$$UnleveredEquityVol = \frac{EquityVol}{(1 + D/E)}, \quad (1)$$

where D/E is firms' debt to equity ratio (market equity) and *Equity Vol* is the measure of equity volatility. Under plausible conditions, similar results using both *Equity Vol* and *UnleveredEquity Vol* cannot be explained by this effect.[20] I also address this issue by directly examining changes in firms' market leverage.

Finally, I measure firms' R&D intensity using *RDShare*, the five-year lag of the industry-year (three-digit SIC code) average of the ratio of R&D expenses to the sum of R&D expenses and capital expenditures. I use this ratio to measure differences in the importance of R&D in the composition of investment, as opposed to differences in the level of investment. The use of an industry average limits the impact of missing data on R&D expenses on the sample. In the Internet Appendix, I consider alternative approaches to measure firm stock return volatility and R&D intensity.[21]

2.2. Financial Crisis Analysis

For inclusion in the initial database in a given year, firms must have COMPUSTAT and CRSP data in both the current year and in 2006. I follow the timeline in Kahle and Stulz (2013) and consider the financial crisis as the period between 2007Q3 and 2010Q1. Motivated by this

[20] More precisely, let E and A denote the value of firms' equity and assets, respectively. Let also σ_E and σ_A denote the value of their respective volatilities. Under plausible conditions, the expression $\sigma_E = \sigma_A(1 + \frac{D}{E})$ provides an upper bound for this mechanical leverage effect. For example, under the assumptions of Merton's model (Merton (1974)), we have $\sigma_E = \sigma_A(1 + \frac{D}{E})\frac{\partial E}{\partial A}$ and $\frac{\partial E}{\partial A}$ declines when firms' debt increases.

[21] For example, I measure the importance of R&D using the ratio of R&D expenses to total assets or using 4-digit SIC codes as the industry definition.

timeline, I restrict the sample to the period between 2005Q3 and 2010Q1. Additionally, I only keep in the initial database firms with non-missing industry SIC codes as well as non-missing values of *Size*, *Cash, Q,* and *Age*. These last variables are defined based on their 2006 values in Appendix B. I compute firm equity volatility at the monthly frequency using daily stock returns. As in the previous analysis, I measure firms' R&D intensity (*RDShare*) using industry (3-digit SIC codes) differences in the importance of R&D in the composition of investment. In order to capture fixed differences across industries over the entire sample, I compute this ratio using all years with available data. In the Internet Appendix, I also consider how this analysis is affected by alternative approaches for measuring R&D intensity.

2.3. Summary Statistics

Table 1 presents summary statistics for the two samples previously described. Panels A and B present summary statistics for the samples used in the analyses focusing on balance sheet shocks and the recent financial crisis, respectively. All variables not defined above are defined in Appendix B.

3. How Do Stronger Balance Sheets Affect Firms' Equity Volatility?

3.1. Empirical Methodology and First Stage

The analysis is based on the estimation of the following specification:

$$\Delta \log(EquityVol)_{irt+1} = \theta_t + \beta \Delta REHoldings_{irt} + \gamma X_{irt} + \varepsilon_{irt} \ , \qquad (2)$$

where $\Delta\log(EquityVol)_{irt+1}$ is the change in log of equity volatility for firm i in region r between years t-5 and $t+1$, $\Delta REHoldings_{irt}$ is the change in the value of firm real estate holdings between years t-5 and t, θ_t are year fixed effects, and X denotes controls. The coefficient of interest is β, which captures the impact of changes in the value of firms' real estate holdings on their subsequent equity volatility. As discussed in Section 2.1, the value of $\Delta REHoldings$ is normalized by the initial value of firms' total assets. In the Internet Appendix, I show that the main results in the paper are robust to normalizing real estate holdings by firms' net PPE.

I use an instrumental variables approach to isolate persistent increases in the value of firms' real estate holdings. This approach has two important components. I first isolate shocks to regions' (MSAs) real estate prices that reflect differences in their exposure to national real estate cycles. I only use the geographically determined availability of land in regions to predict differences in their exposure to national cycles (Glaeser, Gyourko, and Saiz (2008)). The instrumented shocks to the value of firms' real estate holdings then capture the interaction of these shocks with the initial importance of real estate in firms' balance sheets.

More precisely, following Glaeser, Gyorko, and Saiz (2008), persistent shocks to regions' real estate prices are isolated using the following specification:

$$PGrowth_{rt} = NPGrowth_t + \alpha_1 ULand_r + \alpha_2 ULand_r \times NPGrowth_t + \varepsilon_{rt} \ , \qquad (3)$$

where $PGrowth_{rt}$ is the growth of real estate prices in region r between years t-5 and t, $NPGrowth_t$ is the average national growth of the HPI between years t-5 and t, and $ULand_r$ is a measure of the share of land undevelopable for construction in region r. The component of changes in regions' real estate prices that can be explained by their geographically determined exposure to national real estate shocks is the fitted effect of $ULand \times NPGrowth$. This term captures the differential effect of having less available land during national positive shocks (see Section 2.1 and Appendix B for more detail).

Intuitively, national positive shocks to real estate prices have a significantly stronger impact on the local prices of regions with less available land for construction, as builders' ability to respond and bring prices down will depend on the availability of land. As discussed by Glaeser, Gyorko, and Saiz (2008), the availability of land does not predict differential exposures of regions to negative national shocks. Panel A of Table 2 reports results confirming these ideas and estimating Equation (3). Land is unavailable for different reasons (e.g., proximity to oceans or high slopes), and I use this information. More precisely, I estimate (3) using *Uland_1* to *Uland_5* as well as allowing each of these variables to have non-linear effects. I use this specification to isolate shocks to regions' real estate prices that capture their geographically determined exposure to national real estate cycles.

Panel A of Figure 1 confirms that these shocks lead to persistent increases in real estate prices and that they matter for both residential and commercial real estate prices. More precisely, I estimate linear regressions linking the growth of real estate prices (residential and commercial) in a given region between years *t-5* and *t+k* to the instrumented change in real estate prices between years *t-5* and *t* (*PGrowth).* Motivated by Equation (3), the interaction terms *ULand* × *NPGrowth* are used as instruments for *PGrowth* while *Uland* and *NPGrowth* are included as controls.

The instrumented shocks to the value of firms' real estate holdings combine these shocks to local real estate prices with firms' initial ratio of real estate holdings to assets (total assets or net PPE). This interaction is a key aspect of the analysis because shocks to local real estate prices will affect firms through channels other than their balance sheets. Changes in Δ*REHoldings* are predicted using the following specification:

$$\Delta REHoldings_{irt} = \theta_t + \alpha_1 ULand_r + \alpha_2 ULand_r \times NPGrowth_t + \beta_0 RERatio_{it-5} \quad (4)$$
$$+ \beta_1 NPGrowth_t \times RERatio_{it-5} + \beta_2 ULand_r \times RERatio_{it-5}$$
$$+ \beta_3 ULand_r \times NPGrowth_t \times RERatio_{it-5} + \gamma X_{it} + \varepsilon_{it} \ ,$$

where $\Delta REHoldings_{irt}$ is the change in the value of the real estate holdings for firm *i* in region *r* between years *t* and *t-5*, and $RERatio_{it-5}$ is the ratio of the book value of real estate holdings to the book value of total assets in year *t-5*.

More precisely, I estimate (2) using *ULand* × *NPGrowth* × *RERatio* as an instrument for Δ*REHoldings* and all other variables in (4) as controls. This ensures that the estimated effects in (2) only capture the interaction of the previous shocks to real estate prices with the composition of firms' assets prior to the shock.[22] Note that this approach captures the differential exposure of real-estate owning firms (versus other firms) to local real estate shocks, which, in turn, capture the differential exposure of firms' in regions with less available land to national real estate conditions.

Before showing the results, I report the first stage in Panels B and C of Table 2. In the main results, I control for firm characteristics that might be correlated with real estate ownership and include both these characteristics and their interactions with changes in local real estate prices as control variables. I include only controls for arguably exogenous characteristics of firms that are less likely to be determined by real estate ownership. More precisely, in the main results, I control for firm industry, *Size, Age,* and *Cash Flow*. These variables are defined in Appendix B and, as real estate ownership, are measured at *t-5*. They include firm characteristics used

[22] Intuitively, this approach can be interpreted as capturing the following two stages. In the first stage, one estimates equation (4) and isolates the fitted value of *ULand* × *NPGrowth* × *RERatio*. In the second stage, one estimates (2) with all other variables used in (4) as controls and replaces Δ*REHoldings* with this fitted variable from the first stage.

previously to control for the determinants of real estate ownership in real investment equations (Chaney, Sraer, and Thesmar (2012)). Finally, following the approach proposed by Cameron, Gelbach, and Miller (2011), I estimate standard errors by double clustering them by state and year.

3.2. How Do Stronger Balance Sheets Affect Firms' Equity Volatility?

Column (1) in Table 3 reports results from the estimation of equation (2) using the instrumented shocks to the value of firms' real estate holdings. Column (3) in Table 3 reports the results from the estimation of the same specification with changes in unlevered equity volatility as the outcome. Across both results, I find that increases in the value of firms' real estate holdings lead to significant increases in their subsequent equity volatility. For example, Column (1) shows that a shock representing an increase of 10% in the value of firms' total assets leads to an increase of 12.2% in their equity volatility.

I analyze the economic magnitudes of these effects by considering subsamples of firms with significant exposure to real estate. I include the top 50% or 33% of firms in terms of *RERatio*. Using the results, I predict the average effect of typical real estate shocks on the equity volatility of these firms with exposure to real estate.[23] More specifically, I multiply the regression coefficients by the average value of *RERatio* in these subsamples. I then scale this effect by the ratio of the standard deviation of *PGrowth* to the standard deviation of the outcome variable. Following this approach, the magnitude implied by the result in Column (1) is equal to 17.2% and 20.2% for the subsamples of top 50% and 33% real estate owners, respectively.

[23] The goal of the analysis is not study the specific role of real estate shocks in determining firm equity volatility. Instead, the goal is to examine the role of financing constraints and real estate shocks will only significantly affect the financing constraints of a subset of firms that hold real estate assets. Other firms will be exposed to alternative sources of variation in financing constraints which are not captured in these results.

I then analyze the dynamics of these effects. This issue is addressed by estimating the previous results with different horizons for the changes in equity volatility. More precisely, I estimate the same specification as before with $\Delta\ln(EquityVol)_{irt+k}$, the change in equity volatility between year t-5 and $t+k$, as the outcome variable. I first examine the average value of this outcome variable between $k=1$ and $k=3$. These results relate increases in the value of firms' real estate holdings over a given period to their equity volatility in the subsequent three years and examine the persistence of the previous effects. Columns (2) and (4) in Table 3 report the results that show the previous increases in firms' equity volatility are persistent.

Panel B of Figure 1 shows this dynamic in greater detail by separately examining results with $\Delta\ln(EquityVol)_{irt+k}$ as the outcome variable for $k=-5$ to $k=5$. It is useful to consider these results together with the results reported in Panel A of Figure 1 that show how the shock being analyzed affects firms' balance sheets over time. These results show that firms' equity volatility starts immediately increasing as soon as the value of firms' real estate holdings increases. Panel B of Figure 1 also shows that firms' equity volatility reaches its highest level right after the increase in the value of firms' real estate holdings and stays at a higher level in a persistent way.

These patterns precisely match the predictions of the growth-options channel. As soon as real estate holdings increase in value, financing constraints should be relaxed and firms should have more unexercised growth options. As firms start exercising some of these options, the initial increase might be gradually offset over time. In contrast, because of adjustment costs, relaxed frictions are unlikely to have a significant immediate effect on firms' operating and financing structure (e.g., their composition of existing projects). This alternative channel predicts a gradual increase in equity volatility over time after the initial shock to firms' balance sheets.

3.3. Balance Sheet Shocks, Financial Policies, and Real Outcomes

In order to further investigate how stronger balance sheets affect firms' equity volatility, I examine how the previous shocks affect different financing and real decisions of firms. First, consistent with previous research examining such effects (Chaney, Sraer, and Thesmar (2012)), I find that increases in the value of firms' real estate holdings are associated with subsequent increases in firm investment and debt issuance but not with subsequent changes in firms' equity issuance. Columns (1) to (3) in Panel A of Table 4 show these results. Consistent with previous research, these effects imply that firms increase their annual debt issuance and investment by $0.164 and $0.075, respectively, after a persistent increase of $1 in the value of their real estate assets. These increases in investment and debt issuance are arguably limited when compared to the change in firms' borrowing capacity. These specific patterns are predicted by the growth-options channel discussed in Section 1.

Additionally, I find that the previous increases in firm equity volatility are associated with statistically insignificant and economically smaller drops in firm cash flow volatility. Column (4) in Panel A of Table 4 shows this result. This finding also matches the predictions from the growth-options interpretation for the effects. According to this interpretation, stronger balance sheets lead to higher equity volatility because, as firms become better able to respond to new investment opportunities, their value becomes more sensitive to new information about these opportunities. According to this view, these increased fluctuations in value capture greater shifts in investors' expectations about future cash flows and are unlikely to be matched by greater changes in cash flows within a quarter.[24]

[24] Note that cash flow volatility is measured as a standard deviation of quarterly cash flow changes (see Appendix B).

The growth-options channel outlined in Section 1 also predicts that the previous effects should be associated with an improvement in firms' liquidity position, arguably through an increase in unused debt capacity. According to this view, firms' decide to preserve some of their increased debt capacity as an option to finance future investment opportunities. Firms might also convert this increased debt capacity into other sources of liquid funds such as cash. I test these predictions by examining changes in firms' market leverage or net market leverage (market leverage minus cash). Panel B of Table 4 reports results directly examining this hypothesis. The results confirm that the previous sharp increases in firm equity volatility are matched with a drop in firms' market leverage and net market leverage.

3.4. Are the Results Driven by Growth Options?

A major channel through which firms can accumulate growth options is by investing in research and development (R&D). Therefore, to the extent that the previous effects are driven by firms' greater ability to access growth options, it is plausible to expect them to be mostly important among R&D-intensive firms. Moreover, since these acquired options capture firm-specific investment opportunities, the growth-options channel also predicts that the previous increase in equity volatility should be mostly driven by firms' idiosyncratic volatility.

In order to test these predictions, I estimate the previous effects by subsamples, ranked based on firms' initial R&D intensity. R&D intensity is captured by *RDShare* (see Section 2.1). I also decompose firms' overall equity volatility into its idiosyncratic and systematic components and separately analyze the results for these components. I report results using the Fama-French three-factor model to decompose firms' equity volatility but have found similar results using alternative models such as the CAPM.

Table 5 reports the results, which examine the joint importance of R&D intensity and the volatility components. Panel A confirms that the previous effects are driven by increases in the idiosyncratic volatility of R&D-intensive firms.[25] Panel B further shows that these effects are only statistically and economically significant among firms in the top tercile of R&D intensity. On average, 57% of the investment made by firms in this sample is on R&D expenditures, as opposed to capital expenditures.

I then estimate the magnitudes of the effects in an analogous way to Section 3.2. For each sample of R&D-intensive firms, I consider subsamples of firms in the top 50% or 33% in terms of *RERatio*.[26] In the context of Panel A of Table 5 (Column (1)), this magnitude equals 26.6% and 30.1% for the top 50% and 33% real estate owners, respectively. This implies that typical shocks to the value of firms' tangible assets are an important determinant of firms' equity volatility in these broad samples of R&D-intensive firms.

3.5. Do Balance Sheet Shocks Matter for Mature and Large Firms?

To the extent that the results capture fewer financing constraints on firms' ability to access growth options, we should also expect them to not be important among mature and large firms. First, these firms are likely to be less exposed to growth options.[27] Second, previous research

[25] The estimated effects on firms' systematic volatility are not statistically significant and are economically more limited. Lin and Paravisini (2013) find evidence that increased financing constraints increase firms' systematic risks. However, they examine shocks to the balance sheets of firms' banks, as opposed to shocks to firms' own balance sheets, and their analysis might capture alternative economic mechanisms driven by the behavior of banks. For example, increased financing constraints might lead banks to reduce their lending by more during economic downturns and increase the exposure of borrowing firms to downturns through this change in credit supply risk.

[26] While R&D-intensive firms hold less real estate, many of these firms have substantial real estate holdings. In the context of Top50% RD, the average value of *RERatio* among the top 50% and 33% firms in terms of this ratio is 0.183 and 0.208, respectively. The analogous values in the overall sample are 0.231 and 0.277, respectively.

[27] In principle, one alternative possibility to capture the importance of growth options is to look at measures of firms' current investment opportunities, such as *Q*. However, the model outlined in Section 1 illustrates why the growth-options channel outlined there does not predict that the results in the paper should be more important when firms' *current* investment opportunities are more valuable. Intuitively, when firms' current opportunities are more valuable, exercising their real options in the present becomes more attractive. As constrains are relaxed, these firms

suggests that size and age are key predictors of the importance of financing constraints and that mature and large firms might be financially unconstrained (e.g., Hadlock and Pierce (2010)). Following Almeida, Campello, and Weisbach (2004), I classify firms as financially unconstrained if they are in the top 33% of the sample in terms of *Age* and *Size*, and also use a high payout ratio as an additional indicator to determine whether firms are financially unconstrained.

Table 6 reports the results that show that the previous effects are statistically insignificant and economically much less important among mature and large firms. The results confirm this same pattern among high payout firms. These results provide further evidence that the growth-options channel drive the previous effects.

3.6. Identification Concerns

An important concern with the previous results is that local real estate shocks might not only affect local firms through their balance sheets. As local economic conditions change in response to real estate shocks, the fundamentals of local firms could be affected by other channels that also matter for their volatility.[28] This concern will only be relevant if these alternative channels differentially affect firms which own more real estate prior to real estate shocks. However, firms' initial ownership of real estate assets could be related to unobserved firm characteristics that also predict their exposure to these alternative channels. Moreover, it is difficult to find firm-level instruments for real estate ownership. While it is challenging to completely rule out this concern, I address this issue in several different ways.

might use their additional resources to immediately exercise their real options as opposed to keeping a greater ability to exercise them going forward.

[28] Changes in real estate prices will directly affect firms' cost of buying capital in addition to affecting their balance sheet. However, this effect predicts that higher real estate prices reduce firms' equity volatility as firms find it more expensive to respond to investment opportunities.

I start by considering the role of a natural channel through which real estate prices will affect the fundamentals of local firms. Namely, as local real estate prices increase, the aggregate demand for local products and services will increase because of the shock to the net worth of local consumers (e.g., Case, Quigley, and Shiller (2011)). I directly test for the importance of this local aggregate demand channel by examining the differential effect of local real estate shocks on the equity volatility of firms with greater exposure to this channel. I follow Mian and Sufi (2014, hereafter MS) in identifying industries (four-digit NAICS codes) which are more exposed to such local aggregate demand effects. I capture a greater exposure to the local aggregate demand channel with *LocalDemand*, an indicator that equals one if the industry is not classified as tradable by MS.[29] I then estimate how the effect of local real estate price shocks interacts with *LocalDemand* and construct these shocks in the same way as in the previous results.

Panel A of Table 7 reports the results. I include the same set of controls for the determinants of real estate ownership used in the previous results.[30] Column (1) shows that local real estate shocks are associated with a differential increase in the cash flows of firms outside tradable industries. This supports the view that *LocalDemand* captures firms' exposure to local demand conditions. In contrast, Column (2) shows that the previous result is not associated with changes in the equity volatility of firms. This suggests that local demand effects do not lead to significant changes in firm equity volatility. Notice that a persistent increase in the local demand faced by firms will increase their return to investing today but will not necessarily generate more future growth options for firms.

[29] MS classify industries as tradable, non-tradable, construction and other. Industries are classified as tradable if imports plus exports are sufficiently large. Approximately 50% of the firms in the main sample in this paper are classified as being in a tradable industry. I have found that a simple alternative approach which classifies all manufacturing industries as tradable industries leads to conclusions which are similar to the ones here discussed.

[30] These controls include the previous industry controls. *LocalDemand* is defined based on narrow industry definitions and there is significant variation in this variable conditional on the previous industry controls.

If local demand effects are the key drivers of the main results in this paper, these results should become significantly weaker after the inclusion of controls for local demand effects. I estimate the results in Table 3 (Column (1)) and Table 5 (Column (1) of Panel A) including *LocalDemand* and its interaction with predicted real estate shocks as control variables. Panel B of Table 7 reports these results and shows that the estimates in Tables 3 and 5 remain similar and become stronger after the inclusion of these controls. Additionally, I estimate the results including only tradable industries. The results should become less important in this subsample if they capture local demand effects. Panel C of Table 7 reports the results in Table 3 separately estimated in the subsamples of tradable industries and other industries. Columns (1) and (2) show that the results are economically stronger and are only statistically significant when estimated with tradable industries. I then include regional controls while estimating the results with tradable industries. In this specification, the effect of real estate price shocks is identified using only variation within a Census region. This reduces even further the scope for local aggregate demand effects to drive the results. In order to affect the results, differences in local demand conditions can now only take place among tradable industries within a same Census region. Column (3) reports this result which is economically stronger than the one in Table 3 with all industries and without regional controls.

As a next step to address the previous identification concern, I decompose firms' equity volatility into a local and a residual component. This local component captures co-movements in firms' stock returns with a portfolio of stocks located in their same region and also exposed to their local economic conditions. The motivation for this decomposition is that this local component will be more likely to capture news about local economic conditions. Therefore, if the results capture changes in equity volatility driven by local economic conditions, including local demand conditions, they should arguably be better captured by this local component. In contrast with this prediction, I show in the Internet Appendix that the results are mostly important for the residual component of equity volatility, as opposed to the local component of equity volatility.

I then explicitly examine the concern that firm characteristics correlated with real estate ownership could drive the results through alternative channels. I first consider the role of observable firm characteristics correlated with real estate ownership. Panel A of Table 8 relates firm real estate ownership to different firm characteristics. As in the choice of controls in the main results, I focus on fundamental firm characteristics which are less likely to be affected by real estate ownership but now also include *Q* as a measure of investment opportunities. Firms that own more real estate are larger, more profitable, and more mature companies that have less investment opportunities. I examine whether these important and observable firm characteristics could drive the results through alternative channels. In the Internet Appendix, I test whether these characteristics significantly predict the effect of real estate shocks on firm equity volatility after controlling for real estate ownership. The only variable that predicts a statistically significant differential effect of real estate shocks on firm equity volatility is *Q*. Moreover, given the sign of correlation between *Q* and real estate ownership, this predicted effect leads the results to become weaker.

Additionally, I examine the sensitivity of the results to the inclusion of these observable characteristics as controls for real estate ownership. I replicate the results in Table 3 (Column (1)) and Table 5 (Column (1) of Panel A) both including and excluding this set of controls.[31]

[31] Note that this set of controls includes additional variables relative to the ones used in Tables 3 and 5. As in Tables 3 and 5, I include both these variables and their interaction with real estate price changes as controls.

Panel B of Table 8 reports the results which show that the main effects analyzed in this paper become stronger after we include controls for the previous observable firm characteristics. The results also suggest that this difference between estimates is not economically large.

While the previous analysis examines the role of observable firm characteristics, one might still be concerned that unobservable characteristics might affect the results in different ways. I address this issue by contrasting the importance of real estate ownership with the ownership of other tangible assets. I test if the equity volatility of firms with greater ownership of other tangible assets is differentially affected by local real estate shocks. I measure the ownership of other tangible assets (net PPE) as a percentage of total assets in an analogous way to *RERatio* and denote this variable as *OtherPPERatio*. Panel C of Table 8 reports the results. Real estate shocks are associated with a statistically insignificant differential drop in the equity volatility of firms that initially own more other tangible assets. This analysis suggests that the results are not driven by unobservable firm characteristics related to tangible asset ownership.

There might still be a concern that a unique set of unobservable characteristics only drives firms' decisions to own real estate assets, as opposed to tangible assets in general. As a final strategy to address this concern, I note that the results in the paper are only important in samples where the growth options channel is arguably relevant. Table 5 shows that shocks to the value of firms' real estate holdings are not associated with changes in firm systematic volatility or changes in the idiosyncratic volatility of firms which are not intensive in R&D. Table 6 shows that real estate balance sheet shocks are not related to changes in firm equity volatility in subsamples of older, larger, and high payout firms. In order to drive the results, this identification concern has to be relevant only in the same subsamples where the growth options channel is predicted to be relevant.[32]

4. Financial Crisis Analysis

As a final step, I provide evidence that the previous analysis linking firm equity volatility to relaxed financing constraints is consistent with broader patterns on the equity volatility of R&D-intensive firms. I study the equity volatility of R&D-intensive firms during the recent financial crisis, a period where financing constraints are arguably more important.[33] While the results in this analysis are more subject to identification concerns when compared to the ones in the previous analysis, they help to address external validity concerns with the previous results.

The previous analysis suggests that increased financing constraints by R&D-intensive firms during the recent financial crisis should lead to a differential drop in their equity volatility. Figure 2 examines how the cross-sectional relationship between firms' equity volatility and R&D intensity, which I label R&D volatility gap, changes during the crisis. R&D intensity is captured by *RDShare* (see Section 2.2). This gap sharply drops to its historically lowest levels around the recent financial crisis. Moreover, most of this drop in the R&D volatility gap into negative and historically low values takes place around the third quarter of 2008, near the bankruptcy of Lehman Brothers.

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[32] Another concern is that the results could be capturing the direct effect of the volatility of real estate assets. It is challenging to reconcile this interpretation with two important findings in the paper. First, the fact that the results are driven by R&D-intensive firms which own less real estate (see Section 3.4). Second, the fact previously discussed that the results are less relevant for the local component of firm equity volatility.

[33] For example, Duchin, Ozbas, and Sensoy (2010), Almeida et al. (2012), and Becker and Ivashina (2014) provide evidence suggesting an increase in importance of financing constraints and a drop in credit supply during the crisis. This analysis only requires that the crisis was associated with an increase in the importance of financing constraints for a significant group of highly innovative firms. This analysis does not rely on the assumption that financing constraints by corporations were predominant factors in driving changes in their aggregate or average investment during the crisis.

In order to analyze the role of financing constraints in explaining this pattern, I consider the role of firms' cash holdings prior to the crisis. In the absence of other differences across firms, higher cash holdings prior to the crisis should mitigate the effect of financing constraints during the crisis. I examine if the previous differential drop in the equity volatility of R&D-intensive firms is less pronounced for firms with higher initial cash holdings. An important issue is that firms' initial cash holdings are endogenously determined and they could predict firms' exposure to economic shocks taking place during the crisis period. Note that while it is natural to imagine that firms will choose cash holdings based on the exposure of their value to shocks, it is less clear how the sensitivity of their volatility to shocks affects and relates to their cash choices. This approach relies on the following identification assumption. The past cash holdings of R&D-intensive firms do not differentially predict the exposure of firm equity volatility to economic shocks during the crisis when compared to the cash holdings of other firms. In other words, concerns about the endogeneity of cash holdings should not be differentially important for R&D-intensive firms.[34]

There are different sources of evidence providing support to this identification assumption. Panel A in Table 9 examines the differential change in the volatility of R&D-intensive firms across different periods of the financial crisis.[35] The results show no statistically significant effects in samples of firms that have high cash holdings prior to the crisis. It is natural to imagine that firms in very top of the cash holdings distribution in the U.S. faced limited financial constraints during the recent financial crisis (Kahle and Stulz (2013)). Therefore, this evidence suggests that economic shocks do not differentially affect the volatility of R&D-intensive firms

[34] One alternative approach is to use differences in the timing of firms' debt maturity prior to the crisis to predict their financial exposure to the crisis (Almeida et al. (2012)). However, this strategy requires focusing on shocks affecting firms over a narrow period of time and, following Kahle and Stulz (2013), the results here examined focus on a long timeline of events.

[35] I follow Kahle and Stulz (2013) in the definition of these periods.

during the crisis. This result is reasonable since previous research has argued that a main economic shock during the crisis was an aggregate demand shock (Mian and Sufi (2014)). The evidence in Section 3.6 suggests that such shocks might not affect firms' equity volatility. Additionally, Duchin, Ozbas, and Sensoy (2011) provide evidence that past cash holdings do not significantly predict changes in firm investment in response to aggregate demand shocks outside the crisis. Despite this evidence, it is challenging to rule out the possibility that the endogeneity of cash holdings prior to the crisis leads to a violation of the previous identification assumption.

Panel B reports results examining how changes in the link between firm equity volatility and *RDShare* across different periods of the financial crisis relate to firms' initial cash holdings. The results show that changes in the R&D volatility gap during the first year of the crisis are unrelated to firms' initial cash holdings. The importance of cash holdings then sharply increases around the fall of Lehman and remains significant in the last year of the crisis.[36]

In order to evaluate the economic magnitude of these effects, I estimate the required increase in firms' cash holdings to fully offset the average drop in the R&D volatility gap around the fall of Lehman. The results imply that an increase in firms' cash holdings by 0.41, equivalent to 1.73 standard deviations of *Cash*, would fully offset the drop in the R&D volatility gap around the fall of Lehman.

Table 10 shows that these effects are robust to using differences in firms' net leverage (leverage minus cash) prior to the crisis to predict differences in firms' financial exposure to the fall of Lehman. Both the timing and the magnitude of the effects remain very similar. The effects

[36] Becker and Ivashina (2014) propose an approach to isolate time-series fluctuations in credit supply and provide evidence that there is a sharp and large drop in credit supply during the crisis with the same timing as these effects.

imply that a drop in firms' net leverage equivalent to 1.83 standard deviations of *NetLeverage* would fully offset the drop in R&D volatility gap during the fall of Lehman.

Finally, I examine whether differences in firms' past cash holdings predict subsequent increases in the R&D volatility gap prior to the financial crisis. In the Internet Appendix, I provide direct evidence that this link is not present outside the financial crisis. This addresses the concern that such a link might exist even in the absence of sharp changes in the importance of financing constraints.

Taken together, this analysis suggests that broader patterns on the equity volatility of R&D-intensive firms around the recent financial crisis are consistent with the idea that financing constraints play an important role in determining this volatility.

5. Conclusion

This paper provides evidence that an important determinant of higher levels of equity volatility among R&D-intensive firms are fewer financing constraints on their ability to access growth options. I examine the importance of this effect by studying how shocks to the value of firms' tangible assets (real estate) affect their subsequent equity volatility. I estimate the effect of increases in the value of firms' real estate holdings by combining instrumented shocks to local real estate prices with pre-existing differences across firms in the importance of real estate assets in their balance sheet. Based on this approach, I find that persistent increases in the value of firms' real estate holdings lead to significant and persistent increases in firms' subsequent equity volatility. The analysis suggests that these effects are only important among R&D-intensive firms and are driven by firms' greater ability to access growth options after financing frictions are reduced. Moreover, this analysis implies that typical shocks to firms' balance sheets are an economically important determinant of firms' equity volatility among broad samples of R&D-intensive firms that hold some real estate.

Across a range of tests, I address the concern that local real estate shocks might affect the volatility of local firms through alternative channels, and that this effect might be differentially important for firms that initially own more real estate. While completely ruling out this concern is challenging, I contrast several predictions from the previous growth-options channel with the ones from possible alternative channels. This evidence broadly supports the predictions from the growth-options channel. Additionally, I address the external validity of these results by examining changes in the equity volatility of R&D-intensive firms during the recent financial crisis. I find that the previous growth-options channel is consistent with important patterns in the equity volatility of R&D-intensive firms during the crisis.

Taken together, these results suggest caution when interpreting higher levels of equity volatility as a reflection of non-fundamental trading or limits in firms' ability to insulate their value from economic risks. In the presence of imperfect capital markets, higher equity volatility can be a reflection of fewer financing frictions as frictions limit firms' ability to increase their exposure to economic risks usually associated with higher firm value and economic growth. These findings suggest how the underlying source of higher equity volatility can matter in determining the potential implications of higher equity volatility for firm value and welfare. These findings also have implications for the value and determinants of risk-management policies. They suggest that financially constrained firms might not want to hedge a significant portion of the fluctuations in their value not because of constraints or costs in their ability to hedge these risks but because of their incentives to increase their exposure to such risks.

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Appendix A: Stylized Model of Investment with Collateral Constraints

Firms live for three periods (t = *0, 1, 2*). There are two types of capital goods (tangible and intangible). As in models of investment with growth options (e.g., Berk, Green, and Naik (1999)), firms' capital is tied to specific projects. The cash flows generated by project p at time t are given by $y_{pt} = A_{pt}F(k_{pt}^{T}, k_{pt}^{INT})$, where k_{pt}^{T} and k_{pt}^{INT} denote firms' stock of tangible and intangible capital, respectively. I assume that $F(k^T, k^{INT}) = \min\left\{\frac{k^T}{\alpha}, \frac{k^{INT}}{(1-\alpha)}\right\}$. This makes sure that firms use tangible and intangible assets in a fixed proportion and abstracts away from changes in the composition of capital. Let $k = \min\left\{\frac{k^T}{\alpha}, \frac{k^{INT}}{(1-\alpha)}\right\}$, which can be interpreted as one unit of capital. Note that firms will choose their capital such that $k^T = \alpha k$ and $k^{INT} = (1-\alpha)k$. Also note that one can write $y_{pt} = A_{pt}k_{pt}$. For simplicity, there is no depreciation for both types of capital. q^T and q^{INT} denote the price of tangible and intangible capital, respectively. These prices are known by firms at the beginning of period *t=0*, and remain constant over time and across states of the world. The analysis focuses on firm-level volatility. Let $q = \alpha q^T + (1-\alpha)q^{INT}$, which is the price of capital. Also for simplicity, interest rates are normalized to zero. Firms are risk neutral and their objective function is given by $V_0 = d_0 + d_1 + d_2$, where d_t is the dividend paid in time *t.*

I assume that projects can be liquidated by the firm at no loss (market prices) at *t=2* (terminal date). The liquidation value of one unit of capital from project p for firms before the terminal date is given by $q^T k_{pt}^{T} + \delta q^{INT} k_{pt}^{INT}$, where $\delta < 1$. In other words, tangible assets can be liquidated, but there is some inefficiency in the early liquidation of intangible assets. The key point is that capital becomes illiquid once it is invested in a specific project.

Following Kiyotaki and Moore (1997), firms have access to one-year loans subject to limited enforcement. Lenders protect themselves from the threat of repudiation by collateralizing the firms' assets. As in their framework, I assume that firms are able to negotiate the debt down to the liquidation value of the assets pledged as collateral. There is a competitive credit market with unconstrained and risk-neutral lenders. I also assume, for simplicity, that there are no state-contingent contracts. This assumption is plausible given that states in the model are firm-specific and is relaxed below. Given this set-up, firms can borrow b_t in time t subject to the following collateral constraint: $b_t \leq q^T k_{t+1}^{T}$. This constraint implies that firms can pledge at most αq^T when financing one unit of capital. Therefore, the minimum down payment to finance one unit of investment is given by $\gamma \equiv q - \alpha q^T = (1-\alpha)q^{INT}$. I also allow firms to hold a liquid asset (cash). From a firm's perspective, borrowing b_t and holding it as cash until *t+1* is the same as not borrowing b_t because debt payments are constant across states and there is no default in equilibrium. I assume that issuing debt and holding cash is less attractive by imposing an arbitrarily small cost ε of issuing debt. Below I consider the case where firms might also want to hold cash or manage their liquidity through additional tools.

The timing of events is as follows. At *t=0* firms start with some initial capital k_0 invested in project 1 and no other wealth or debt. Firms can borrow, pay dividends and have the option to expand this project, which pays cash flows in both *t=1* and *t=2*. More precisely, firms choose k_{11}. After decisions are made, uncertainty is resolved. There are two states (high and low) denoted by $s \in \{H, L\}$ and with probabilities given by $p(H) \equiv p$ and $p(L) = 1 - p$. At *t=1*, some cash flows from project 1 are realized ($y_{11} = A_{11}(s)k_{11}$). It is not possible to invest in project 1 at *t=1*, but firms can liquidate some or all of its capital invested in project 1, i.e., firms choose $k_{12}(s) \leq k_{11}$. If *s=L*, there are no new projects and firms have no investment opportunities. It is possible to have $A_{11}(L) < 0$, which captures temporary losses associated with the project. Note that creditors always have priority over secured assets. When firms incur losses, they can always use residual assets (after creditors are paid), liquidating them to cover losses. Alternatively, firms can liquidate the assets in bankruptcy with limited liability. If *s=H*, firms have a new investment opportunity and can invest in project 2, which pays cash flows only at *t=2*, i.e., firms choose k_{22}. Firms pay creditors and can also borrow and pay dividends. At *t=2*, cash flows from projects are realized and firms pay creditors and dividends. If *s=L*, these cash flows are given by $y_{12}(L) = A_{12}(L)k_{12}(L)$. If *s=H*, these cash flows are $y_{12}(H) + y_{22} = A_{12}(H)k_{12}(H) + A_{22}k_{22}$. I assume that $A_{1t}(L) \leq A_{1t}(H)$ and $A_{1t}(H)$>0. As I discuss in greater detail below, the illiquidity associated with project 1 is assumed to be important enough so that it is never optimal for firms to liquidate project 1 before *t=2*.

In the comparative statics analysis, I focus on the volatility of firms' stock returns around the resolution of uncertainty. Let $V_0(s)$ denote the value of firms' equity right after the information on *s* is revealed. Assuming for simplicity that investors are risk neutral, firms' market value right before uncertainty is resolved is given by $E(V_0)$, where the expectation is based on the initial distribution of states. Therefore, the stock return around the resolution of uncertainty is given by $R(s) = \frac{V_0(s)}{E(V_0)}$. One can write the volatility of this stock return as $\sigma_0 \equiv \sigma(R(s))$, where the standard deviation is also based on the initial distribution of states. More generally, one can think of firms as being affected by multiple information shocks. This stylized model focuses only on one such shock.

The goal is to analyze $\frac{\partial \sigma_0}{\partial q^T}$, i.e., how changes in the price of tangible assets impact their stock return volatility. For any given variable *X*, let $\tilde{X} \equiv \frac{\partial X}{\partial q^T}$. Because there are only two states of the world, using simple algebra, one can show that $\frac{\partial \sigma_0}{\partial q^T} > 0$ if $\widetilde{R(H)} > \widetilde{R(L)}$ and $\frac{\partial \sigma_0}{\partial q^T} < 0$ if $\widetilde{R(L)} > \widetilde{R(H)}$. This captures the broader and simple fact that firms' stock return volatility will increase (decrease) if changes in the price of tangible assets create more value in good (bad) or high (low) value states.

Before examining the different cases, it is useful to consider how changes in q^T can affect firms in this model. Since interest rates are normalized to zero for simplicity, there is no cost in using capital in this model. Therefore, increases in q^T do not affect the optimal level of investment but only relax financing constraints. This collateral channel can be seen by noticing that increases in q^T do not affect the minimum required down payment but increase firms' initial net worth. The intuition for this effect is as follows. Changes in the price of tangible assets have two effects. On the one hand, they increase firms' ability to borrow against their current assets. On the other hand, they increase the required cash outflows to purchase new assets. Because firms' borrowing is only tied to tangible assets but cash outflows are tied to all assets, the first effect is more important. Another reason for this gap, outside this model, is the existence of leverage effects (Kiyotaki and Moore (1997)).

When financing constraints are relaxed, firms face the following trade-off. On the one hand, they have the option to use their increased borrowing capacity to invest in project 1 at *t=0*. As firms invest in the project, they convert liquid funds into illiquid assets. Recall that firms do not find it optimal to liquidate illiquid assets at *t=1* unless they need to do this. On the other hand, firms can preserve their increased access to liquid funds for *t=1*. They can preserve their borrowing capacity for *t=1* by not borrowing at *t=0*. This greater availability of liquidity at *t=1* will allow firms to respond more to investment opportunities in state H. It will also reduce liquidity costs in state L. In other words, firms face a choice between using their increased liquidity right away at *t=0* or preserving it and using it to manage risks at *t=1*.

The growth-options channel emerges under the following two conditions. First, most risks faced by firms at *t=1* are risks about their investment opportunities, as opposed to liquidity or cash-flow risks. Second, the value of investing in project 2 is high so that firms decide to preserve a substantial portion of their increased liquidity at *t=0* for *t=1*. In the simple model here considered, corner solutions are optimal and this last condition leads firms to preserve all their increased liquidity. Under these conditions, relaxed financing constraints affect firms real decisions only by increasing their investment in state *H* at *t=1*.

Under these conditions, the effect of relaxed constraints is therefore to provide firms with more growth options (more investment in project 2) and this increases the volatility of their value. Firms do not use their liquidity right away to invest and choose to keep these unexercised growth options. As firms move forward, both their investment and their volatility increase. Notice that relaxed constraints only create value for firms in future high value states. This increases the volatility of firm value as we move forward.

More formally, I illustrate this channel by imposing that firms face only risks about their investment opportunities. I assume that $A_{11}(H) = A_{11}(L) \equiv A_{11}$, $A_{12}(H) = A_{12}(L) \equiv A_{12}$. The idea that investing in project 2 is valuable (relative to project 1) is captured by the following assumption: $pA_2\left(1 - \frac{A_{11}}{\gamma}\right) > A_{11} + A_{12}$. Finally, as previously discussed, I assume that investing in a project generates an illiquid claim by imposing that $f < \left(\frac{A_{12}(H)+1}{A_2+1}\right)$. I denote these conditions as (C1).

These assumptions imply that firms never find it optimal to liquidate project 1 before t=2. The first option firms have is to liquidate the project and keep the proceeds. This is never optimal because liquidation is costly and project 1 leads to positive profits. The second option is to liquidate project 1 to invest in project 2. The value created by this strategy at *t=1* when *s=H* is $\left(A_2 f - A_{12}(H)\right) - (1 - f)$, where $f = \frac{\delta(1-\alpha)q^{INT} + \alpha q^T}{q}$ is the fraction of assets' value recovered in an early liquidation. The previous condition on f implies that this decision to liquidate is not optimal. Note that liquidating project 1 at *t=0* to possibly invest in project 2 at *t=1* is even less attractive than doing this at *t=1* when *s=H.*

Also note that since $A_{11} > 0$, the firm will never be forced to liquidate assets at *t=1*. The firm can always raise $A_{11}k_{11} + \alpha q^T k_{11} - b_0$ at *t=1* and the collateral constraint at *t=0* implies that $b_0 \leq \alpha q^T k_{11}$. Therefore, $k_{12}(s) = k_{11}$.

Since the value of having liquidity to invest in the new project is high, firms will preserve their initial liquidity and not expand their initial investment. They will choose $b_0 = 0$ and $k_{11} = k_0$. More formally, we can write $V_0(L) = qk_0 + A_1 k_{11}$ and $V_0(H) = qk_0 + A_1 k_{11} + A_2 k_{22}$, where $A_1 = A_{11} + A_{12}$. These expressions imply that $E(V_0) = qk_0 + A_1 k_{11} + pA_2 k_{22}$. Notice also that, given a choice of b_0, $k_{11}$and k_{22} are uniquely determined. From the budget constraint at *t=0*, we have that $b_0 = q(k_{11} - k_0)$ and we can think of firms' initial decision as the choice of k_{11}. Notice that if *s=H,* then the firm will invest all available resources in project 2, since $A_2 > 0$ and there is no cost in using capital. Therefore, firms will use all available funds to make down payments and will choose $k_{22} = \frac{(A_{11}+\alpha q^T)k_{11}-b_0}{\gamma}$. Using the budget constraint at *t=0*, we can write this last expression as $k_{22} = -\left(1 - \frac{A_{11}}{\gamma}\right) k_{11} + \frac{qk_0}{\gamma}$. Intuitively, when firms invest in one unit of illiquid capital at t=0, they are giving up one more unit of capital in project 2. This effect is mitigated by the fact that project 1 generates profits at t=1 that can be used for a down payment. This expression allows one to uniquely determine $E(V_0)$ for a given choice of k_{11} and estimate $\frac{\partial E(V_0)}{\partial k_{11}}$. This leads to the conclusion that $\frac{\partial E(V_0)}{\partial k_{11}} < 0$ iff $pA_2\left(1 - \frac{A_{11}}{\gamma}\right) > A_1$, one of the conditions listed in (C1).

Given that firms choose $k_{11} = k_0$, one can write $V_0(L) = qk_0 + A_1 k_0$ and $V_0(H) = qk_0 + A_1 k_0 + A_2\left[\frac{(A_{11}+\alpha q^T)k_0}{\gamma}\right]$. Proposition 1 can now be stated.

<u>Proposition 1</u>: *If condition (C1) holds, then* $\frac{\partial \sigma_0}{\partial q^T} > 0$.

Proof. From above, there are expressions for $V_0(L)$ and $V_0(H)$. Note that $\widetilde{R(S)} = \left[\left(\frac{\widetilde{V_0(S)}}{V_0(S)}\right) - \left(\frac{\widetilde{E(V_0)}}{E(V_0)}\right)\right]\left(\frac{V_0(S)}{E(V_0)}\right)$. Since $V_0(H) > V_0(L)$, if $\frac{\widetilde{V_0(H)}}{V_0(H)} > \frac{\widetilde{V_0(L)}}{V_0(L)}$ then $\widetilde{R(H)} > \widetilde{R(L)}$ and $\frac{\partial \sigma_0}{\partial q^T} > 0$. From the above expressions for $V_0(L)$ and $V_0(H)$, simple algebra leads to the condition that $\frac{\widetilde{V_0(H)}}{V_0(H)} > \frac{\widetilde{V_0(L)}}{V_0(L)}$ iff $A_1 + q > A_{11} + \alpha q^T$. This last condition holds given (C1).

In the Internet Appendix, I formally analyze the case where liquidity risks are more important. I assume that the value of new investment opportunities is small. I also assume that, in the bad state, negative cash flows from the initial project at *t=1* force firms to inefficiently liquidate some of their capital invested in the project. Therefore, financing constraints affect liquidation losses in the bad state. When financing frictions relax, firms face a trade-off between using the additional liquidity to invest in project 1 at *t=0* or to hedge liquidity risks at *t=1*. When project 1 generates limited value, firms will use the additional liquidity to hedge liquidity risks. Therefore, relaxing financing frictions makes firms' value less sensitive to liquidity shocks and reduces the volatility of their value.

I have also considered what happens if expanding the initial project is profitable. Firms will decide to use their additional liquidity to invest in project 1. Consequently, relaxing financing constraints can increase the volatility of their value by endogenously limiting their ability to adjust in response to liquidity shocks at *t=1*.

The previous analysis allowed firms to manage their liquidity only by preserving their debt capacity, i.e., borrowing less at *t=0*. The intuition and results in Proposition 1 are robust to allowing firms to use additional liquidity management tools. A first alternative for firms would be to hold cash. As previously discussed, in the absence of some cost of issuing debt, firms are indifferent in this model between borrowing b_t and holding it as cash until *t+1* and not borrowing b_t. In other words, cash is negative debt in this model, and all that matters for firms is their net debt (debt minus cash). While I assumed the existence of some small cost of issuing debt, it is simple to see what happens to Proposition 1 if one does not impose such cost. There is no change in the constraints faced by firms in making investment decisions. No real decisions or valuations change in equilibrium and Proposition 1 is still valid. The only change is that the firm will become indifferent across multiple financial policies while implementing the same real decision and achieving the same valuation across states. While firms choose $k_{11} = k_0$ they will be indifferent between a range of financial policies at *t=0* (more or less debt-cash) that generate a net debt equal to zero.

Another alternative is to allow firms to use credit lines. One way to model this is to assume that firms are offered a contract that allows them to draw a loan with pre-determined terms if they have a project to invest on. In this contract, firms would pay a fee in the bad state subject to collateral constraints and would have access to a credit line in the good state. The credit line would allow the firm to borrow more than its debt capacity in the good state, allowing the firm to transfer funds from the bad to the good state. Under conditions (C1), the firm always wants to transfer funds from the bad to the good state and allowing for this contract is the same as allowing for complete contracts under collateral constraints. In the Internet Appendix, I show that Proposition 1 still holds if one allows for such state-contingent contracts. It continues to be the case that relaxing financing constraints only increases firm investment at *t=1* in state *s=H*. The difference is that firms now use additional strategies to increase this investment. As before, firms preserve debt capacity at *t=0* (or borrow and hold cash). Additionally, they now also transfer cash flows from state *s=L* to state *s=H* at *t=1*. Relaxed financing constraints allow firms to increase their investment in state *s=H* at *t=1* through these two channels. Note that additional liquidity management tools (subject to collateral constraints) are redundant once one allows for such state-contingent contracts.

Appendix B: Variable Definitions

RERatio is the five-year lag of the ratio of real estate assets (*ppenb* + *ppenli* + *ppenc*) to total assets (*at*). For years after 1998, the value of these variables is defined using the ratio in 1993.

RDShare (Table 5, 7, and 8) is the five-year lag of the industry-year (three-digit SIC code) average of the ratio of R&D expenses to the sum of R&D expenses and capital expenditures.

RDShare (Tables 9-10, Figure 2) is the industry (three-digit SIC code) average of the ratio of R&D expenses to the sum of R&D expenses and capital expenditures, computed using all years of data available.

Size is the log of total assets (*at*).

Age is the number of years since the firm has been listed in COMPUSTAT.

Cash Flow is operating income before depreciation (*oibdp*) divided by the one-year lag of total assets.

Q is the ratio of the total assets (*at*) plus market capitalization (*prcc*×*csho*) minus common equity (*ceq)* minus deferred taxes and investment credit (*txditc*) to total assets (*at*).

Leverage (Tables 2-8) is the ratio of the book value of debt (*dlc* + *dltt*) to the sum of the book value of debt (*dlc* + *dltt*) and market capitalization (*prcc*×*csho*).

Cash (Tables 2-8) is the ratio of cash and short-term investments (*cheq*) to the sum of the book value of debt (*dlc* + *dltt*) and market capitalization (*prcc*×*csho*).

Net Leverage (Tables 2-8) is the difference between *Leverage* and *Cash*.

PGrowth is the (inflation-adjusted) growth of real estate prices in region *r* between years *t-5* and *t,* i.e., the price change divided by the initial price. This can be computed based on residential real estate prices (HPI) or commercial real estate prices (NPI). This can be defined at the MSA level or state level. Unless otherwise stated, this variable is based on MSA residential prices.

NPGrowth is the average value of *PGrowth* across all firms in the sample.

Δ*REHoldings* = *PGrowth*× *RERatio.*

Uland_1 is the share of land in a 50km radius from the city's centroid that has a high slope (greater than 15%).

Uland_2 is the share of land in a 50km radius from the city's centroid that is not in the ocean.

Uland_3 is the share of open water in land area within a 50km radius from the city's centroid.

Uland_4 is the share of woody wetlands in land area within a 50km radius from the city's centroid.

Uland_5 is the share of emergent/herbaceous wetlands in land area within a 50km radius from the city's centroid.

Uland is the share of land unavailable for development within a 50km radius from the city's centroid for one of the reasons captured between *Uland_1* and *Uland_5*.

Sq_Uland_j = *Uland_j*× *Uland_j.*

EquityVol (Tables 2-8, Figure 1) is the annualized standard deviation of daily returns computed over the last 250 trading days of the firm's fiscal year. Only firm-year observations with at least 150 trading days are included.

Unlevered EquityVol is based on equation (1) where *EquityVol* is defined above and D/E is the ratio of the book value of debt (*dlc* + *dltt*) to market capitalization (*prcc*×*csho*).

Δlog(*EquityVol)* is the change in the log of *EquityVol* between years *t-5* and *t*.

Δlog(*Unlevered EquityVol)* is the change in the log of *Unlevered EquityVol* between years *t-5* and *t*.

All other measures of changes in volatility are also computed analogously to Δlog(*EquityVol).*

IEquity Vol (FF Model) is the annualized standard deviation of daily residual returns (returns minus fitted returns from FF Model) computed over the last 250 trading days of the firm's fiscal year.

SEquity Vol (FF Model) is the annualized standard deviation of daily fitted returns (using the FF Model) computed over the last 250 trading days of the firm's fiscal year.

Δlog(*Cash Flow Volatility)* is the difference between the log of the cash flow volatility computed between years *t+1* and *t+5* and the log of the same volatility computed between years *t-9* and *t-5*. Cash flow volatility is computed as the standard deviation of quarterly cash flow changes over the respective period. Cash flow change is the difference between current operating income (*oibdpq*) and the one-quarter lag of operating income divided by the one-year lag of total assets (*at*).

LocalDemand is an indicator that equals one if the industry (4-digit NAICS code) is not classified as tradable by Mian and Sufi (2014).

PPERatio is the five-year lag of the ratio of net property, plant and equipment (*ppent*) to total assets (*at*). For years after 1998, the value of these variables is defined using the ratio in 1993.

OtherPPERatio is the difference between *PPERatio* and *RERatio.*

EquityVol (Tables 9-10, Figure 2) is the annualized standard deviation of daily returns computed over the current calendar month. Only firm-month observations with at least 19 trading days in the calendar month and 150 trading days in the calendar year are included.

Cash (Tables 9-10) is the ratio of cash and short-term investments (*cheq*) to total assets (at).

Leverage (Tables 9-10) is the ratio of the book value of debt (*dlc* + *dltt*) to total assets (*at*).

Net Leverage (Tables 9-10) is the difference between *Leverage* and *Cash*.

Table 1

Summary Statistics

This table presents summary statistics for the main samples used in the paper. The samples are described in Section 2. Panel A presents summary statistics for the sample used in the instrumental variables analysis. Observations are at the firm-year level. Panel B presents summary statistics for the sample used in the financial crisis analysis. Observations are at the firm-month level. All variables are defined in Section 2 and Appendix B.

Panel A: Summary Statistics - Instrumental Variables Analysis

	Obs.	Mean	Std. Dev.	Median
Firm Characteristics and Financial Policies				
RERatio	26,796	0.146	0.129	0.122
Size	26,796	5.28	1.91	5.15
Age	26,796	12.53	8.27	11.00
Cash Flow	26,796	0.164	0.120	0.167
Q	25,653	1.532	0.972	1.242
RDShare	25,330	0.299	0.225	0.289
Leverage	26,210	0.260	0.221	0.211
Cash	26,596	0.106	0.131	0.055
NetLeverage	26,038	0.154	0.297	0.147
Real Estate Variables				
PGrowth	26,796	0.088	0.282	0.050
ΔREHoldings	26,796	0.012	0.051	0.002
Uland_1	26,796	0.097	0.160	0.020
Uland_2	26,796	0.137	0.156	0.050
Uland_3	26,796	0.031	0.025	0.026
Uland_4	26,796	0.028	0.034	0.019
Uland_5	26,796	0.021	0.055	0.009
Equity Volatility Variables				
EquityVol	26,620	0.495	0.327	0.404
Unlevered EquityVol	26,042	0.352	0.246	0.285
Δlog(EquityVol)	23,969	0.025	0.496	0.017
Δlog(Unlevered EquityVol)	23,194	0.020	0.536	0.020
IEquity Vol	26,796	0.464	0.321	0.371
Δlog(IEquityVol)	24,540	0.015	0.483	0.005
SEquity Vol	26,796	0.146	0.105	0.120
Δlog(SEquity Vol)	24,540	0.037	0.795	0.047

Panel B: Summary Statistics - Financial Crisis Analysis

	Obs.	Mean	Std. Dev.	Median
RDShare	203,050	0.376	0.260	0.352
Cash	203,050	0.227	0.237	0.136
Age	203,050	15.70	11.22	12.00
Size	203,050	6.026	1.976	5.988
Q	203,050	2.275	1.616	1.780
EquityVol	203,050	0.116	0.099	0.092

Table 2

Isolating Shocks to the Value of Firms' Real Estate Holdings

This table presents results isolating the instrumented shocks to the value of firms' real estate holdings. Observations are at the firm-year level. Panel A shows results isolating shocks to local real estate prices. Columns (1) to (3) show results linking local changes in real estate prices to the local availability of land for different subsamples, sorted based on the value of national changes in real estate prices. The results are obtained by linear regressions linking *PGrowth* to *ULand* for different subsamples, sorted by *NPGrowth* (See Section 2 for definitions). *NPGrowth Bottom 33%* is the subsample of years in the bottom 33% in terms of *NPGrowth*. The other two subsamples are defined analogously. Columns (4) and (5) show results based on the estimation of equation (3) with different measures of land availability, as well as their non-linear effects. *Uland* is a measure of the total share of land unavailable because of regions' geography. *Uland_1* to *Uland_5* capture shares of land unavailable because of different geographic characteristics of regions (See Appendix B). The sample in Panel A is broader than the one described in Table 1. The sample is contructed in the same way as the one in Table 1, but without the restriction to observations with non-missing values of *ΔREHoldings*. Panel B reports the estimation of the first-stage regression (4) with the sample described in Table 1. The outcome variable in this first-stage regression is *ΔREHoldings*. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: Isolating Local Shocks to Real Estate Prices

	PGrowth				
	NPGrowth Bottom33%	NPGrowth Middle33%	NPGrowth Top33%	All	
	(1)	(2)	(3)	(4)	(5)
ULand	0.001	0.269***	0.715***	0.086**	
	(0.051)	(0.085)	(0.095)	(0.043)	
NPGrowth × ULand				1.859***	
				(0.239)	
NPGrowth × ULand_1					3.126***
					(1.119)
NPGrowth × Sq_ULand_1					-2.246
					(1.171)
NPGrowth × ULand_2					4.117***
					(0.806)
NPGrowth × Sq_ULand_2					-7.501***
					(1.784)
NPGrowth × ULand_3					-0.970
					(3.796)
NPGrowth × Sq_ULand_3					-18.921
					(14.279)
NPGrowth × ULand_4					11.791***
					(3.448)
NPGrowth × Sq_ULand_4					-46.460***
					(16.841)
NPGrowth × ULand_5					6.765***
					(2.246)
NPGrowth × Sq_ULand_5					-13.725***
					(5.231)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	25,380	22,545	24,504	71,777	71,777
R^2	0.31	0.29	0.32	0.34	0.51

Panel B: First Stage	
	ΔREHoldings
	(1)
NPGrowth × ULand_1× RERatio	2.546**
	(1.144)
NPGrowth × Sq_ULand_1× RERatio	-1.372
	(1.653)
NPGrowth × ULand_2× RERatio	3.870***
	(1.108)
NPGrowth × Sq_ULand_2× RERatio	-7.595***
	(2.447)
NPGrowth × ULand_3× RERatio	-1.312
	(2.895)
NPGrowth × Sq_ULand_3× RERatio	-13.746**
	(6.737)
NPGrowth × ULand_4× RERatio	8.090***
	(3.926)
NPGrowth × Sq_ULand_4× RERatio	-28.404**
	(15.364)
NPGrowth × ULand_5× RERatio	5.914**
	(3.032)
NPGrowth × Sq_ULand_5× RERatio	-13.439**
	(6.773)
Year FE	Yes
Observations	34,657
R^2	0.72

Table 3
How Do Stronger Balance Sheets Affect Firms' Equity Volatility?

This table presents results estimating variations of equation (2) using the instrumental variables approach described in Section 3. The sample is the one described in Panel A of Table 1. The only difference across specifications is the outcome variable. As in equation (2), the outcome variable in column (1) is the change in *Log(EquityVol)* between years *t-5* and *t+1*. The outcome variable in column (2) is the difference between the average value of *Log(EquityVol)* across years *t+1, t+2*, and *t+3,* and its value in year *t-5*. The outcome variables in columns (3) and (4) are defined analogously using the unlevered equity volatility. The interaction *ULand* × *NPGrowth* × *RERatio* is used as an instrument for *ΔREHoldings* and all other variables in equation (4) are included as controls. More precisely, the results include year fixed effects, *Uland*, *ULand* × *NPGrowth*, *RERatio*, *RERatio* × *NPGrowth,* and *RERatio* × *Uland* as controls. The different components of land availability (*Uland_1* to *Uland_5*), as well their squared values, are included in this analysis. Firms' industry, as well as *Size, Age,* and *Cash Flow* are also included as controls. These variables are measured in *t-5* and, for each characteristic, firms are sorted (by year) into three groups. Both indicators for each of these groups as well as their interactions with local real estate prices are included as controls. All variables are defined in Section 2 and Appendix B. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

	Δlog(EquityVol)		Δlog(UnleveredEquityVol)	
	1-Year Horizon	3-Year Horizon	1-Year Horizon	3-Year Horizon
	(1)	(2)	(3)	(4)
ΔREHoldings	1.222***	1.066**	1.895***	2.294**
	(0.466)	(0.493)	(0.811)	(0.991)
Year FE	Yes	Yes	Yes	Yes
Observations	24,054	20,013	23,276	19,121
R^2	0.21	0.13	0.13	0.09

Table 4

Balance Sheet Shocks, Financial Policies and Real Outcomes

This table presents results analyzing the changes in financial policies and real outcomes associated with the previous equity volatility results. The results are based on the estimation of the same specification used in Column (1) of Table 3 with different outcome variables. Panel A reports results examing changes in outcome variables between the post and pre periods. The post period is between years t+1 and t+5. The pre period is between year t-9 and t-5. *ΔInvestment, ΔDebt Issuance*, and *ΔEquity Issuance* are changes in the average values of *Investment, Debt Issuance*, and *Equity Issuance* across these two periods, respectively (see Appendix B for details). *ΔCash Flow Volatility* is the difference in *Cash Flow Volatility* across these periods, where *Cash Flow Volatility* is the standard deviation of quarterly cash flow changes within a period (see Appendix B for details). Panel B estimates results with changes in firms' market leverage. *ΔLeverage_1* is the difference in market leverage between years *t-5* and *t* *ΔLeverage_2* is the difference between firms' market leverage in year *t-5* and the average value of their leverage in years *t* and *t+1*. Changes in net leverage are defined analogously using firms' net leverage. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: Firm Investment, Security Issuance, and Cash Flow Volatility

	ΔInvestment	ΔDebt Issuance	ΔEquity Issuance	Δlog(Cash Flow Volatility)
	(1)	(2)	(3)	(4)
ΔREHoldings	0.207**	0.164**	0.047	-0.445
	(0.098)	(0.064)	(0.033)	(0.429)
Year FE	Yes	Yes	Yes	Yes
Observations	15,729	13,396	15,894	17,223
R^2	0.10	0.03	0.05	0.05

Panel B: What Happens to Firm Leverage?

	ΔLeverage_1	ΔLeverage_2	ΔNet Leverage_1	ΔNet Leverage_2
	(1)	(2)	(3)	(4)
ΔREHoldings	-0.344**	-0.437**	-0.462***	-0.584***
	(0.162)	(0.213)	(0.193)	(0.190)
Year FE	Yes	Yes	Yes	Yes
Observations	29,295	26,659	28,911	26,238
R^2	0.11	0.11	0.09	0.10

Table 5
Are the Results Driven by Growth Options?

This table presents results estimating the same specification used in Column (1) of Table 3 in different subsamples and with different components of firms; equity volatility. The outcome variable is replaced with changes in measures of firm idiosyncratic (*IVol*) or systematic volatility (*SVol*) over the same period. These measures are based both on the Fama-French Three-Factor Model and their construction is described in Appendix B. The subsamples are constructed by sorting firms (by year) based on *RDShare*, the five-year lag of the industry-year (three-digit SIC code) average of the ratio of R&D expenses to the sum of R&D expenses and capital expenditures. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: Results by R&D Intensity and Volatility Components

	Top50% RD		Bottom50% RD	
	Δlog(IVol)	Δlog(SVol)	Δlog(IVol)	Δlog(SVol)
	(1)		(3)	(4)
ΔREHoldings	2.357***	0.491	0.204	-0.455
	(1.026)	(1.276)	(0.617)	(0.837)
Year FE	Yes	Yes	Yes	Yes
Observations	11,694	11,694	11,431	11,431
R^2	0.20	0.25	0.07	0.07

Panel B: Results by R&D Intensity and Volatility Components (Continuation)

	Δlog(IVol)	
	Top Tercile RD	Other
	(1)	(2)
ΔREHoldings	2.514**	0.365
	(1.069)	(0.538)
Year FE	Yes	Yes
Observations	8,070	15,055
R^2	0.20	0.20

Table 6

Do Balance Sheet Shocks Matter for Mature and Large Firms?

This table presents results estimating the same specification used in Column (1) of Table 3 in different subsamples. The outcome variable is replaced with changes in measures of firm idiosyncratic (*IVol*). *Top Age, Top Size*, and *Top Payout* include firms in the top 33% of the sample for *Age, Size,* and *Payout*, respectively. The sample used to determine these percentiles is broader than the one described in Table 1 (see Section 4.2 for discussion). These variables are measured in year *t-5* and firms are sorted by year. For each variable, the subsamples *Bottom Age, Bottom Size*, and *Bottom Payout* include all remaining firms. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

	Δlog(IVol)					
	Top Age	Bottom Age	Top Size	Bottom Size	Top Payout	Bottom Payout
	(1)	(2)	(1)	(2)	(1)	(2)
ΔREHoldings	0.418	1.721**	0.367	1.564**	0.549	1.360**
	(0.501)	(0.821)	(0.597)	(0.736)	(0.588)	(0.673)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15,521	9,159	10,992	13,758	10,686	13,026
R^2	0.24	0.19	0.34	0.17	0.26	0.18

Table 7

Addressing Concerns About Local Aggregate Demand Effects

This table presents results addressing concerns that local aggregate demand effects could drive the previous effects (see Section 3.6). Panel A reports results from linear regressions linking the outcome variables to *PGrowth* × *LocalDemand* and controls. The changes in outcome variables are measured between years *t-5* and *t+1*. The interaction *ULand* × *NPGrowth* × *LocalDemand* is used as an instrument for *PGrowth* × *LocalDemand.* The controls include year fixed effects, *Uland*, *ULand* × *NPGrowth*, *LocalDemand*, *LocalDemand* × *NPGrowth*, and *LocalDemand* × *Uland.* Firms' industry, as well as *Size, Age,* and *Cash Flow* are also included as controls. Both these controls and the land availability variables are included in an analogous way to Table 3. Panel B reports results including additional controls in the specification in Table 3 (column (1)). The controls include *LocalDemand, LocalDemand* × *NPGrowth, LocalDemand* × *Uland*, and *ULand* × *NPGrowth* × *LocalDemand*. Panel C reports results from the estimation of the specifications in Table 3 (column (1)) and Table 5 (column (1) of Panel A) in different subsamples. The classification of firms into tradable industries and other industries is based on 4-digit NAICS codes (see Section 3.6). Column (3) includes additional controls in the specification in Table 3. The additional controls include separate indicators for each Census region as well as interactions of all these indicators with *NPGrowth*, *RERatio* and *NPGrowth* × *RERatio*. All variables are defined in Section 2 and Appendix B. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: How Local Aggregate Demand Affects Firms' Equity Volatility?

	ΔCash Flow	Δlog(EquityVol)
	(1)	(3)
PGrowth × *LocalDemand*	0.681***	-0.026
	(0.248)	(0.147)
Year FE	Yes	Yes
Observations	62,153	46,840
R^2	0.19	0.24

Panel B: How Sensitive are the Results to Controling for Local Aggregate Demand Effects?

	Δlog(EquityVol)	Δlog(IVol)
	All Firms	Top50% RD
	(1)	(2)
ΔREHoldings	1.171**	2.483***
	(0.484)	(1.110)
Year FE	Yes	Yes
Local Demand Controls	Yes	Yes
Observations	24,054	11,694
R^2	0.21	0.20

Panel C: Restricting the Analysis to Tradable Industries and Including Regional Controls

	Δlog(EquityVol)		
	Tradable Industries	Other Industries	Tradable Industries
	(1)	(2)	(3)
ΔREHoldings	1.639***	0.707	1.372**
	(0.658)	(0.548)	(0.613)
Year FE	Yes	Yes	Yes
Regional Controls			Yes
Observations	14,594	9,329	14,594
R^2	0.21	0.21	0.21

Table 8

Addressing Additional Concerns About Alternative Channels

This table presents results addressing additional identification concerns with the previoulsy estimated effects of balance sheet shocks (see Section 3.6). Panel A reports results of linear regressions linking *RERatio* (outcome variable) to different firm characteristics (*Age*, *Size*, *Cash Flow*, *Q*). The regressions include year fixed effects and industry controls. Columns (1) to (4) show results from regressions including one characteristic and column (5) reports the results from a regression including all charateristics at the same time. The reported coefficients are the regression coefficients scaled by the ratio of the standard deviation of the characteristic to the standard deviation of *RERatio*. The reported standard errors are standard errors for these scaled coefficients. Panel B reports results from the estimation of the specifications in Table 3 (column (1)) and Table 5 (column (1) of Panel A) with alternative sets of controls. Columns (1) and (3) report results with industry controls but without the controls for firm characteristics and their interaction with *PGrowth*. Columns (2) and (4) report results which include all controls in Tables 3 and 5, and add *Q* to the set of firm characteristics used as controls for real estate ownership. *Q* is included in an analogous way to the other firm characteristics. Panel C reports results examining if shocks to local real estate prices are associated with differential effects on firms owning other types of PPE, different from real estate. This specification is analogous to the ones in Table 3 (column (1)) and Table 5 (column (1) of Panel A). *ΔREHoldings= PGrowth × RERatio* is replaced with *PGrowth × Other PPE Ratio*, where *Other PPE Ratio* is the initial ratio of other PPE (other than real estate assets) to firms' total assets. This specification also replaces *RERatio* with *Other PPE Ratio* in the definition of all control and instrumental variables. All variables are defined in Section 2 and Appendix B. Standard errors are heteroskedasticity robust and double clustered at the state and year level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: What Firm Characteristics are Related to Real-Estate Ownership?

	RERatio				
	(1)	(2)	(3)	(4)	(5)
Age	0.116***				0.031
	(0.057)				(0.059)
Size		0.160***			0.136***
		(0.022)			(0.020)
Cash Flow			0.061***		0.051***
			(0.010)		(0.012)
Q				-0.076***	-0.079***
				(0.019)	(0.017)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	26,705	26,705	26,705	25,569	25,569
R^2	0.04	0.05	0.04	0.04	0.08

Panel B: Sensitivity of Results to Controlling for Observable Firm Characteristics

	Δlog(EquityVol) All Firms		Δlog(IVol) Top50% RD	
	(1)	(2)	(3)	(4)
ΔREHoldings	1.011**	1.208***	1.901**	2.157**
	(0.475)	(0.455)	(0.908)	(1.083)
Controls		Yes		Yes
Year FE	Yes	Yes	Yes	Yes
Observations	24,054	24,054	11,694	11,694
R^2	0.21	0.21	0.21	0.21

Panel C: Falsification Test Using Ownership of Other Tangible Assets

	Δlog(EquityVol) All Firms	Δlog(IVol) Top50% RD
	(1)	(2)
PGrowth × OtherPPERatio	-0.270	-0.179
	(0.425)	(1.045)
Year FE	Yes	Yes
Observations	24,054	11,694
R^2	0.21	0.21

Table 9

R&D Volatility Gap and Cash Holdings During the Financial Crisis

This table presents results analyzing how changes in the link between R&D intensity and equity volatility during the financial crisis relate to firms' cash holdings prior to the crisis The sample is the one described in Panel B of Table 1. The unit of observation is a firm-month and the sample covers the period between 2005Q3 to 2010Q1. The dependent variable is *Log(EquityVol)*, the monthly volatility of firms' stock returns. Panel A reports of a linear regression linking *Log(EquityVol)* to interactions of *RDShare* with time indicators for different periods of the financial crisis. This regression includes the following controls: *Age, Size*, and *Q* (all measured in 2006), as well as their interactions with the previous time indicators. For each industry (3-digit SIC code), *RDShare* is the average ratio of the R&D expense to the sum of this expense and capital expendituires. *Initial_Cash* is firm cash holdings over assets measured in 2006. The different subsamples are defined based on different percentiles of *Initial_Cash*. For example, Top 25% Initial Cash includes firms above the top 25th percentile of Initial_Cash. Panel B reports results of a linear regression linking *Log(EquityVol)* to interactions of *RDShare×Initial_Cash* with time indicators for different periods of the financial crisis. This regression includes the following controls: *RDShare, Initial_Cash* and the variables *Age, Size*, and *Q* (all measured in 2006), as well as their interactions with the previous time indicators. Finally, the specification includes both time and firm fixed effects. All variables are defined in Section 2 and Appendix B. Standard errors are heteroskedasticity robust and double clustered at the firm and month level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: Does the R&D Volatility Gap Drops Among High-Cash-Holding Firms?

	Log(EquityVol)			
	Top 25% Initial Cash	Top 20% Initial Cash	Top 15% Initial Cash	All Firms
	(1)	(2)	(3)	(4)
RDShare× FirstYear(2007Q3-2008Q2)	0.014	0.074	0.11	-0.044
	(0.040)	(0.052)	(0.064)	(0.031)
RDShare× Lehman(2008Q3)	-0.054	-0.036	0.025	-0.209***
	(0.048)	(0.055)	(0.068)	(0.024)
RDShare× Post-Lehman(2008Q4-2009Q1)	-0.022	-0.032	-0.031	-0.157***
	(0.039)	(0.049)	(0.064)	(0.024)
Time FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Observations	49,794	39,961	30,152	197,490
R^2	0.07	0.07	0.07	0.10

Panel B: Is the Drop in R&D Volatility Gap Less Important Among Firms with Higher Cash Holdings?

	Log(EquityVol)	
	Period 2005Q3 -2010Q1	Period 2006Q3 -2010Q1
	(1)	(2)
RDShare× Initial_Cash × FirstYear(2007Q3-2008Q2)	0.040	-0.025
	(0.095)	(0.094)
RDShare× Initial_Cash × Lehman(2008Q3)	0.292***	0.267***
	(0.088)	(0.088)
RDShare× Initial_Cash × Post-Lehman(2008Q4-2009Q1)	0.386***	0.329***
	(0.113)	(0.109)
RDShare× Initial_Cash × LastYear(2009Q2-2010Q1)	0.313***	0.250***
	(0.092)	(0.089)
Time FE	Yes	Yes
Firm FE	Yes	Yes
Observations	203,050	160,655
R^2	0.10	0.10

Table 10

R&D Volatility Gap and Net Leverage During the Financial Crisis

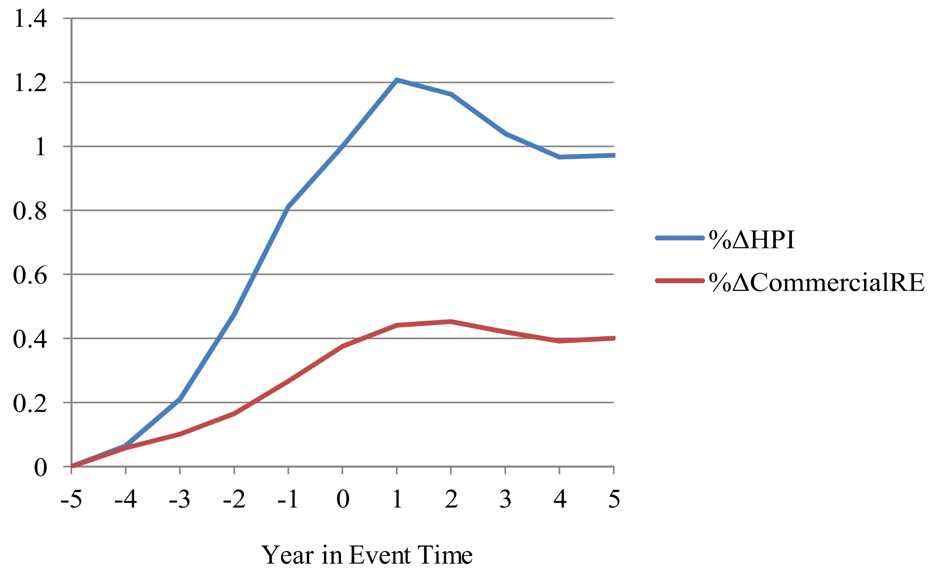
This table presents results analyzing how changes in the link between R&D intensity and equity volatility during the financial crisis relate to firms' net leverage (leverage minus cash holdings) prior to the crisis. All results are analogous to the ones reported in Panel B of Table 9, but replace *Initial_NetLeverage* with *Initial_Cash*. *Initial_NetLeverage* is the value of *NetLeverage* in 2006. All variables are defined in Section 2 and Appendix B. Standard errors are heteroskedasticity robust and double clustered at the firm and month level. *, **, and *** indicate statistical significance at the 10%, 5%, and 1%, respectively.

	Log(EquityVol)	
	Period 2005Q3 -2010Q1	Period 2006Q3 -2010Q1
	(1)	(2)
RDShare× Initial_NetLeverage× FirstYear(2007Q3-2008Q2)	-0.009	0.041
	(0.058)	(0.057)
RDShare× Initial_NetLeverage × Lehman(2008Q3)	-0.149***	-0.120**
	(0.056)	(0.057)
RDShare× Initial_NetLeverage × Post-Lehman(2008Q4-2009Q1)	-0.230***	-0.181***
	(0.053)	(0.051)
RDShare× Initial_NetLeverage × LastYear(2009Q2-2010Q1)	-0.220***	-0.172***
	(0.054)	(0.052)
Time FE	Yes	Yes
Firm FE	Yes	Yes
Observations	202,484	160,223
R^2	0.10	0.10

Figure 1
Persistence of Real Estate Price Shocks and Equity Volatility Increases

This figure reports two sets of results. Panel A reports results examining the dynamics of the local real estate shocks studied in the instrumental variables analysis. Linear regressions linking the growth of real estate prices in a given region between years *t-5* and *t+k* to the instrumented change in these same prices between years *t-5* and *t* (*PGrowth*) are estimated. The interaction terms *ULand* × *NPGrowth* are used as instruments for *PGrowth*, while *Uland* and year fixed effects are included as controls. The figure captures the estimated effects from *k=-4* to *k=5* with both changes in residential (HPI) and commercial (NPI) real estate prices as outcomes. Panel B presents results analyzing the dynamics of changes in equity volatility. The results use the same specifications as Column (1) in Table 3 with changes in equity volatility between years t-5 and t+k as outcomes (k=-4 to k=5). The figure plots the estimated effects for different horizons.

Panel A: Instrumented Increase of 100% in Local HPI Between Years -5 and 0



Panel B: Increase in Stock Return Volatility Over Time

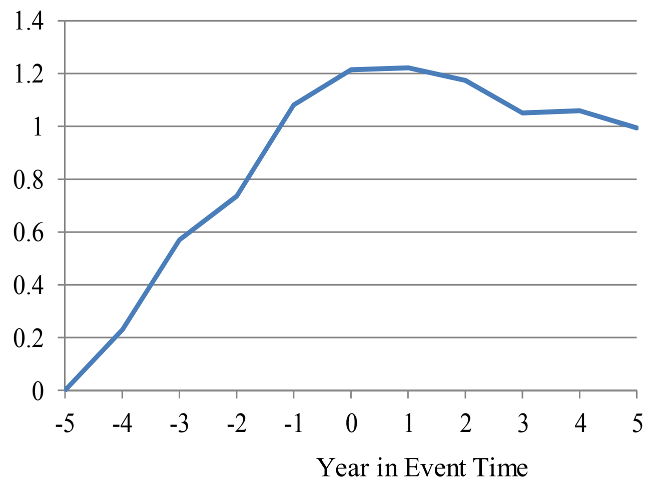
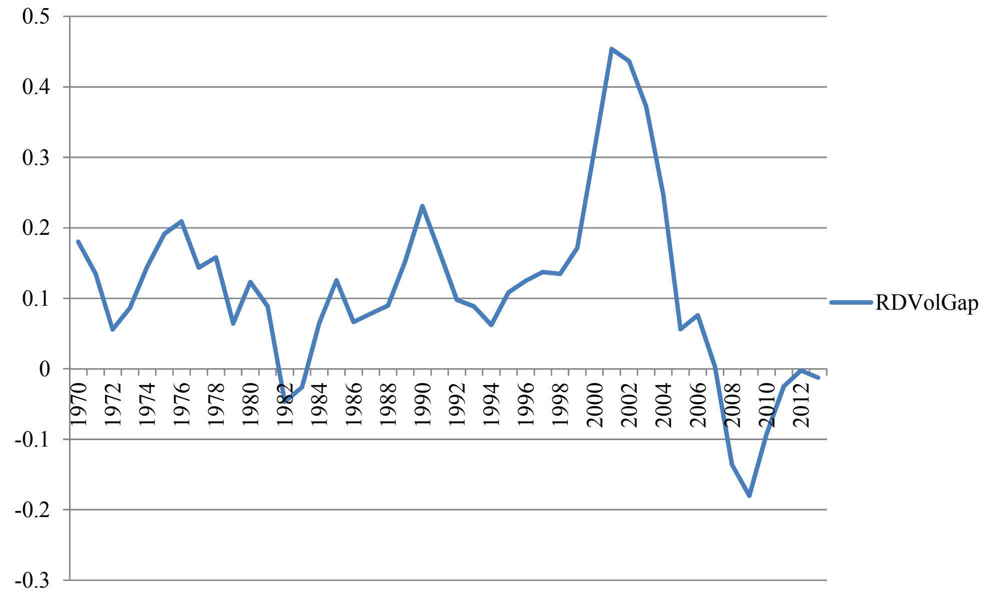


Figure 2
R&D Volatility Gap Over Time

This figure presents the time-series patterns of *RDVolGap*. This variable is constructed using monthly data. For each month between 1970 and 2013, *RDVolGap* is estimated using a cross-section regression with firm-level data. This regression estimates the link between the log of firm monthly equity volatility (dependent variable) and a constant, *Age, Q, Size*, and *RDShare*. *RDVolGap* is the regression coefficient on *RDShare*. Panel A plots the annual averages of this variable for each calendar year between 1970 and 2013. Panel B plots the quarterly averages of this variable for each quarter between years 2005 and 2011.

Panel A: Broad Time-Series Patterns in the R&D Volatility Gap



Panel B: R&D Volatility Gap Around the Financial Crisis