DEBT OVERHANG AND MATURITY STRUCTURE

by

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ABSTRACT

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This study examines the effect of the maturity structure of debt on corporate investment utilizing industry deregulation and alternatively high natural gas price as the exogenous shock to investment opportunities. When the shock occurs, the relation between shorter debt maturity and investment becomes more positive, and exclusively so in firms more likely to be susceptible to investment distortions caused by debt overhang. This study finds no evidence that shorter debt maturity exacerbates debt overhang. The evidence is consistent with Myers (1977) that shorter debt maturity alleviates investment distortions caused by debt overhang.

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Debt Overhang and Maturity Structure

1. Introduction

Debt financing appears to be convenient judging by its historic use as a major source of outside capital for firms. However, debt can also potentially cause firms to bypass otherwise valuable projects, an effect commonly known as debt overhang (Myers, 1977).[1] Debt overhang arises because firms acting in the interests of equity holders bypass investment opportunities in which significant value is expected to be captured by debt holders rather than equity holders. Researchers argue that firms may alleviate the adverse effect of debt overhang by manipulating the maturity structure of debt, but disagree on whether shorter or longer maturity is the solution.

On the one hand, Myers (1977) hypothesizes that shorter debt maturity – due to more frequent rollover and the associated repricing of debt claims – reduces excess value captured by debt holders and thereby alleviates debt overhang. Consequently, shorter debt maturity is preferable for firms susceptible to debt overhang, such as firms with valuable investment opportunities and risky debt. On the other hand, Diamond and He (2014) and He and Xiong (2012) argue that shorter debt maturity can exacerbate debt overhang, particularly when business or market conditions deteriorate. During such conditions, equity holders face higher costs associated with repaying maturing debt, which increase their incentives to default and undermine investment incentives. Alternative longer debt maturity is preferable in expectation of such conditions in firms susceptible to debt overhang. It is unclear which argument prevails

[1] Empirical studies that provide indirect evidence on the existence of debt overhang include, among others, McConnell and Servaes (1995), Ahn, Denis, and Denis (2006), Smith and Watts (1992), Rajan and Zingales (1995), Jung, Kim, and Stulz (1996), Goyal, Lehn, and Racic (2002), Johnson (2003), Billett, King, and Mauer (2007).

and whether the effect of debt maturity on debt overhang is material, as the existing literature provides only circumstantial evidence.

This study directly examines the effect of debt maturity on debt overhang. It utilizes two exogenous shocks that alter the set of investment opportunities. One is industry deregulation and the other is high price of natural gas. As these shocks alter investment opportunities, the affected firms should respond by increasing investment.

Given the shock to investment opportunities, this study examines if a firm's investment response relates to the maturity of the firm's debt.[2] In essence, it utilizes a difference-in-differences approach, in that it compares the difference in investment resulting from the shock for firms that differ in debt maturity. Statistically, it tests whether debt maturity alters the relation between investment and the exogenous shock indicator. Furthermore, to ascertain if the effect is related to debt overhang, this study performs the analysis in firms that are more likely to be susceptible to debt overhang. As a counterfactual, it also performs the test in firms that are less likely to be susceptible to overhang.

This study first focuses on industry deregulation as the exogenous shock. Among firms susceptible to debt overhang, it finds a positive effect of shorter debt maturity on the relation between the change in investment and the deregulation shock indicator. That is, firms with

[2] This study constructs measures of debt maturity using long-term debt. The maturities of long-term debt are usually determined over prior years and long-term debt is typically publicly held, difficult for renegotiation on short notice (Almeida et al., 2011). The existing literature also implies that transaction and adjustment costs could constrain firms from quickly and fully adjusting debt maturity that has been determined based on cumulative decisions over prior years (Fama and French, 2002, Baker and Wurgler, 2002, and Leary and Roberts, 2005). The likely predetermined and sticky maturity structure of long-term debt allows for a direct assessment of the extent to which debt maturity alters investment distortions following the shock.

shorter debt maturity increase investment more during deregulation years than firms with longer debt maturity. No such relation is found in counterfactual tests using firms that are less susceptible to debt overhang (i.e., firms with few investment opportunities or firms with low leverage). This evidence is consistent with Myers's (1977) argument that shorter debt maturity alleviates debt overhang.

Next, this study examines whether shorter debt maturity exacerbates debt overhang when business conditions of individual firms deteriorate. It partitions the sample of firms susceptible to debt overhang into firms facing adverse business conditions and firms facing favorable business conditions, as measured by the probability of default from the Merton model. It then examines whether debt maturity affects the relation between investment and the shock indicator. For firms facing favorable business conditions, this study finds a positive effect of shorter debt maturity on change in investment in response to the deregulation shock. The effect is statistically insignificant for firms facing adverse business conditions. Even under adverse business conditions, shorter debt maturity does not appear to exacerbate debt overhang as compared to longer debt maturity. The results are consistent with the idea that shorter debt maturity alleviates debt overhang, particularly for firms facing favorable business conditions.

This study employs an alternative, market-wide measure of business conditions that splits the sample years. It examines whether shorter debt maturity exacerbates debt overhang during low state of the market. It identifies the state of the market using annual returns on the U.S stock market and alternatively the National Bureau of Economic Research (NBER) definitions of economic expansion and recession. Among firms more susceptible to debt overhang, during high markets, the relation between the change in investment and the shock indicator is positively and

significantly related to shorter debt maturity. No such relation is found during low markets. The results indicate that shorter debt maturity alleviates debt overhang in high markets while the effect is attenuated in low markets. Notably, there is no evidence that shorter debt maturity exacerbates overhang or that longer maturity alleviates overhang in low markets.

As an alternative exogenous shock to investment opportunities, this study uses years of high price of natural gas to examine the effect of debt maturity on natural gas producers' investment. According to Gilje and Taillard (2016), natural gas producers face greater investment opportunities in high natural gas price environments. This study examines whether debt maturity affects the investment response of gas producers susceptible to debt overhang in periods of high gas prices. It finds that shorter debt maturity has a positive effect on the relation between investment and high price indicator. There is no such effect in the counterfactual test using gas producers less susceptible to debt overhang. This evidence provides further support for the notion that shorter maturity alleviates debt overhang.

Overall, the evidence is consistent with the hypothesis that the maturity of debt significantly affects the strength of debt overhang. Consistent with Myers (1977), shorter maturity alleviates debt overhang. The effect is present in highly levered firms with valuable investment opportunities, particularly when the firms are facing favorable business conditions or in high state of the market. The attenuation of the effect in the firms facing adverse business conditions or during low markets has two possible explanations. First, it is possible that the costs associated with shorter maturity increase in adverse business conditions or low markets. However, they are insufficient to outweigh the benefit of shorter maturity with respect to reducing debt overhang. Second, it is possible that firms are generally less responsive to new

investment opportunities in those conditions. Regardless of the reason, there is no evidence that shorter debt maturity exacerbates debt overhang or longer debt maturity alleviates overhang.

This study makes several contributions to the existing literature. By examining potential underinvestment following a positive investment opportunity shock among firms more susceptible to overhang, it provides direct empirical evidence on the effect of debt maturity structure on debt overhang. As such, this study contributes to the theoretical literature that examines debt overhang and studies that provide indirect evidence of debt overhang (McConnell and Servaes, 1995, Ahn, Denis, and Denis, 2006, Smith and Watts, 1992, Rajan and Zingales, 1995, Jung, Kim, and Stulz, 1996, Goyal, Lehn, and Racic, 2002, Johnson, 2003, Billett, King, and Mauer, 2007, among others). This study provides evidence consistent with the existence of debt overhang and documents a significant effect of debt maturity on the strength of debt overhang.

Furthermore, this study contributes to the capital structure literature by documenting that shorter debt maturity alleviates debt overhang, consistent with indirect evidence provided in Barclay and Smith (1995), Guedes and Opler (1996), Goyal, Lehn, and Racic (2002), and Johnson (2003). Existing studies suggest significant costs of shorter debt maturity especially in adverse business conditions or low markets (Diamond and He, 2014; He and Xiong, 2012). Given these costs, why would companies ever shorten debt maturity? This study presents evidence that shorter debt maturity has the benefit of alleviating investment distortions in firms with valuable investment opportunities and a large amount of debt outstanding. In contrast, longer debt maturity provides no such benefit even at the bad times.

The rest of this study is organized as follows. Section 2 discusses the related literatures. Section 3 describes sample construction and the empirical designs. Section 4 presents univariate

tests. Section 5 presents the multivariate regressions. Section 6 presents robustness tests. Section 7 examines the natural gas industry. Section 8 concludes.

2. Literature review

Myers (1977) argues that firms with risky debt outstanding may pass up valuable investment opportunities if a sufficient amount of the investment payoffs are used to pay the debt. This debt overhang and the underinvestment that it causes destroy firm value. Highly levered firms are more likely to face debt overhang and pass up good projects because more of the firm value generated by new investment is shared by debt holders. Subsequent empirical studies provide circumstantial evidence consistent with the existence of debt overhang. McConnell and Servaes (1995) and Ahn, Denis, and Denis (2006) document that in firms with valuable investment opportunities, leverage is negatively related to firm value. Giroud et al (2012) document that leverage reduction is associated with subsequent improvement in operating performance for firms that are likely subject to debt overhang. Smith and Watts (1992), Rajan and Zingales (1995), Jung, Kim, and Stulz (1996), Goyal, Lehn, and Racic (2002), Johnson (2003), and Billett, King, and Mauer (2007) report a negative relation between leverage and growth opportunities, which is consistent with the idea that firms with growth opportunities reduce leverage as they seek to alleviate debt overhang.[3]

Admati et al (2018) and Dangl and Zechner (2021) study debt overhang related to the liability side of the balance sheet. The studies suggest that equity holders resist the repurchase of outstanding debt using available internal funds or new equity capital. This debt repurchase

[3] An alternative explanation for the negative relation between leverage and growth opportunities is that firms time the market by issuing more equites when their market valuations are high (Rajan and Zingales, 1995, and Baker and Wurgler, 2002).

would transfer wealth from equity holders to remaining debt holders. It would reduce the risk to remaining debt holders because of lower volume of remaining debt claims. This is a form of debt overhang. As such, these studies provide indirect support for the existence of debt overhang.

With respect to debt maturity, Myers (1977) hypothesizes that debt of shorter maturity alleviates debt overhang by reducing debt holders' share of benefit from new profitable investment. In particular, debt of longer maturity is associated with greater uncertainties on future ability to repay debt due to the longer time it takes for repayments. As such, the debt holders would share more benefit from an increase in the firm value generated by the investment. Consequently, the incentives of equity holders to undertake the investment are lower. In contrast, debt of shorter maturity is less sensitive to changes in the firm value arising from new profitable investment, due to more frequent rollover and repricing. Repricing for new debt incorporates the good news and the value of maturing debt is less affected by the news. The debt holders share less benefit from new profitable investment and equity holders have stronger incentives to undertake the investment. Myers predicts that firms with more growth opportunities choose debt of shorter maturity. Barclay and Smith (1995), Guedes and Opler (1996), and Goyal, Lehn, and Racic (2002) document evidence consistent with that prediction.

Diamond and He (2014) suggest that debt of shorter maturity can impose stronger overhang when the value of firms' assets-in-place deteriorates and falls short of the value of liabilities. In these circumstances, rolling over debt, referred to as the practice of issuing new debt to repay maturing debt, becomes more costly. A greater amount of debt maturing sooner imposes higher costs for equity holders to fully repay maturing debt, incentivizing earlier default. The early default eliminates future investment opportunities and growth of immediate

investment, distorting investment incentives. Similarly, He and Xiong (2012) argue that higher rollover costs of shorter-maturity debt during low markets increase equity holders' incentive to default, a stronger overhang imposed by shorter maturity debt.

Related to but distinct from Diamond and He (2014) and He and Xiong (2012), several articles study other costs of shorter maturity debt that could lead to underinvestment. Diamond (1991) studies liquidity risk of short maturity debt. He argues that the lenders have incentives to sub-optimally liquidate the firm when bad news arrives, as the value in liquidation may be higher for the lenders. Facing suboptimal liquidation, the firm is likely to forgo investment. The liquidity risk makes shorter maturity debt more costly to the borrower, who responds by choosing longer debt maturity or adopting more conservative investment policies.

Almeida, Campello, Laranjeira, and Weisbenner (2011) document that refinancing risk of shorter maturity debt impairs investment in poor credit market conditions. They find a negative relation between the proportion of long-term debt maturing soon and investment change around the credit crisis of 2007 for a wide sample of firms, and no significant relation in non-crisis periods.

Harford, Klasa, and Maxwell (2014) argue that firms use cash to mitigate the refinancing risk of shorter maturity debt and the potential underinvestment. They document a positive association between shorter maturity debt and cash holdings, particularly during years of poor credit market conditions and high refinancing risk. They further document a positive effect of cash holdings on investment in firms with shorter maturity debt, which strengthens in poor credit market conditions. Their evidence is consistent with the idea that refinancing risk of shorter maturity debt adversely affects investment.

3. Sample construction, identification, and empirical design

3.1. Sample construction

The sample in this study includes the U.S. public firms with accounting data available from the Compustat Industrial Annual database (Compustat). The sample includes companies in the industries experiencing deregulations during 1977–2006. The sample is limited to this period because it is when deregulation events are concentrated. The industries include entertainment, petroleum and natural gas, telecommunications, and transportation. Although the utilities industry also experienced deregulations during the period, this study excludes utilities due to possible significant effects of regulations on their financial and investment decisions. This study further excludes companies with total book assets of less than 25 million in constant 1994 dollars. For the empirical analysis, this study requires data on the change in capital expenditures during consecutive years, and therefore require that at least two consecutive years of data be available for the company. To alleviate the effects of outliers, this study truncates all accounting variables at 1% and 99%. It also discards observations with leverage or debt maturity greater than one or less than zero due to concerns about the reliability of such observations. This study supplements accounting data with data on stock returns and stock prices from the Center for Research in Security Prices (CRSP). These screens result in a sample of 10,861 firm-year observations.

All variables used throughout the study are defined and described in greater detail in Appendix A. Appendix B provides the summary statistics of the main variables of interests in the study. The average net capital expenditure investment is approximately 5.5% of total assets. Average one-year change in the investment is around 0.4% of total assets. On average, the book

value of long-term debt maturing within three (five) years is about 18.5% (30%) of total book debt. The average leverage ratio is approximately 31.4%.

3.2. Identification and empirical design

This study exploits an exogenous shock that alters the investment opportunity set. Given the shock, a firm not facing debt overhang responds by capturing new profitable projects and should exhibit an increase in investment. A similar firm facing debt overhang is likely to forgo new profitable projects and should exhibit less of an increase or possibly a decrease in investment. To study whether debt maturity affects debt overhang, this study examines whether debt maturity modifies firms' investment response to the shock.

This study utilizes two alternative exogenous shocks to investment opportunities. One is industry deregulation and the other is high price of natural gas. The focus is first on industry deregulation. According to Ovtchinnikov (2010), among others, industry deregulation represents a positive shock to the investment opportunities. Deregulation increases operating freedom and alleviates price controls, enabling deregulated firms to take advantage of higher prices and future profitability by investing more. Deregulation often reduces bureaucratic costs and profits captured by the government, thereby increasing profitability of investment. Deregulation reduces and eliminates industry-wide market inefficiencies and applies primarily to the industry as a whole. It is unlikely to be driven by factors related to individual firms and is outside the control of individual firms.

This study starts with all deregulations listed by Ovtchinnikov (2010) except for those in the utilities industry. Some industries experience multiple deregulation events in one year or in consecutive years. Some deregulations may have greater effect on the industry. In order to focus

the research on deregulations likely to be unexpected and have major and positive impacts on investment opportunities, this study implements the following procedure.

This study estimates the industry annual abnormal return during a deregulation year as the average abnormal return across all sample firms in the industry. Firm abnormal returns are firm stock returns adjusted for the Fama and French 25 size and book-to-market benchmark portfolio returns. Appendix C reports the industry abnormal return for each deregulation year along with the respective t statistics. A deregulation year with a positive industry abnormal return that is statistically significant at the 0.10 level or less is identified as the year when firms of the industry received a significant positive deregulation shock to investment opportunities.

This study implements the analysis as the difference-in-differences approach, for the industries having at least one deregulation shock. It examines how the *ex-ante* variation in debt maturity is related to investment responses to an increase in investment opportunities following the deregulation shock. It compares the difference in investment resulting from the deregulation shock for firms that differ in debt maturity. For simplicity and consistency, later this study refers to deregulation shock as deregulation. Years of deregulation shock are deregulation years and the other years are non-deregulation years.

Furthermore, this study performs the analysis for firms susceptible to debt overhang. A necessary condition for the existence of debt overhang, according to Myers (1977), is the availability of investment opportunities. In addition, highly levered firms are more likely to face debt overhang. Reflecting these conditions, this study identifies highly levered firms with valuable investment opportunities as the firms susceptible to debt overhang. Firms with market leverage above the median during the sample period are highly levered firms. Other firms are

firms with low leverage.[4] Firms with market-to-book ratio greater than one are firms with valuable investment opportunities (high-growth firms). Other firms are firms with few investment opportunities (low-growth firms). The effects of debt overhang should be more pronounced in highly levered high-growth firms as compared to counterpart low-growth firms or low-leverage firms.

4. Univariate analysis

In Appendix D, this study reports mean and median one-year changes in investment of highly levered high-growth firms around deregulation years. The one-year change is measured between the last fiscal year ending before the calendar year of deregulation (year t–1), and the following fiscal year (year t). The firms are sorted by debt maturity at the end of year t–1. Debt maturity is measured as the ratio of book value of long-term debt maturing within three years or within five years to the book value of total debt (Maturity_3yr or Maturity_5yr). Firms with the ratio above the sample median are firms with shorter debt maturity or shorter-maturity firms. Other firms are firms with longer debt maturity or longer-maturity firms. For comparison, this study reports the statistics for non-deregulation years as well.

The results of Appendix D reveal that shorter-maturity firms experience a significantly greater increase in investment than longer-maturity firms as a response to the shock in deregulation years. In non-deregulation years, the changes in investment of shorter-maturity firms and longer-maturity firms exhibit no significant differences. Furthermore, shorter-maturity firms increase investment more in deregulation years than they do in non-deregulation years.

[4] This study reports the test results using market leverage as the measure of leverage. Alternatively, book leverage is used as the measure of leverage. The results are similar and are not tabulated for brevity.

For longer-maturity firms, the investment changes in deregulation and non-deregulation years are not significantly different. The evidence indicates that shorter debt maturity allows firms facing debt overhang to invest more in response to the arrival of investment opportunities during deregulation, while longer debt maturity impedes that response. It is consistent with the argument of Myers (1977) that shorter debt maturity alleviates debt overhang.

5. Multivariate analysis

In this section, this study uses multivariate regressions to examine how debt maturity relates to the change in investment resulting from deregulation while simultaneously controlling for factors that may influence the investment change.

In the baseline model, the dependent variable is the change in investment measured as one-year change in net capital expenditure normalized by total book assets. The independent variables include debt maturity at the end of year t–1. Higher values of debt maturity correspond to greater proportions of shorter-maturity debt or shorter debt maturity. To measure the investment opportunity shock, this study includes a deregulation indicator (Shock) and interact it with debt maturity. The interaction captures how debt maturity alters the relation between change in investment and deregulation. Control variables include market-to-book ratio, market leverage, size, tangibility, and sales growth, all measured as of year t–1.

5.1. Debt overhang and the relation between debt maturity and change in investment

As the first step, this study estimates the baseline model for highly levered high-growth and low-growth firms. The results are reported in Appendix E. In the high-growth firms, the coefficients of the interaction of debt maturity and the deregulation indicator are 0.049 for the three-year debt maturity measure and 0.045 for the five-year debt maturity measure, positive

and statistically significant at the 0.05 level and 0.01 level, respectively. The evidence indicates that shorter debt maturity is positively associated with the relation between change in investment and deregulation. It is consistent with the idea that shorter-maturity firms respond to investment opportunities by increasing investment more or underinvesting less than longer-maturity firms.

As an alternative measure of debt maturity, this study uses an indicator variable for shorter-maturity firms (Smat_3yr and Smat_5yr). This yields similar results. In the high-growth firms, the coefficients of the interaction of debt maturity and the deregulation indicator are 0.018 for the three-year maturity and 0.023 for the five-year maturity measure, statistically significant at the 0.05 and 0.01 levels, respectively.

In the low-growth firms, the coefficients of the interaction of debt maturity and the deregulation indicator are statistically insignificant. The positive effect of shorter debt maturity on change in investment in response to deregulation is present only in highly levered high-growth firms, the firms susceptible to debt overhang. The effect is absent in counterpart low-growth firms, the firms less susceptible to debt overhang.

This study re-estimates the baseline model but also includes the triple interaction of debt maturity, the deregulation indicator, and an indicator for the high-growth firms (High Q). The triple interaction provides a formal test for the difference in the effects of debt maturity on investment response to deregulation between the high-growth and low-growth firms. The results are reported in Appendix F. The coefficients of the triple interaction are 0.070 for the three-year maturity measure and 0.063 for the five-year maturity measure, statistically significant at the 0.10 and 0.05 levels, respectively. Using indicators for shorter debt maturity, the coefficients of

the triple interaction are 0.021 and 0.026, statistically significant at the 0.10 and 0.05 levels, respectively. The results demonstrate that the relation between shorter debt maturity and the investment response to deregulation is significantly more positive for the high-growth than the low-growth firms.

Altogether, the results document a positive effect of shorter debt maturity on investment response to deregulation that is associated with the susceptibility of firms to debt overhang. The evidence is consistent with the hypothesis that shorter debt maturity alleviates debt overhang.

5.2. Robustness of the maturity-investment relation and its association with overhang

Throughout the analysis, deregulation years when the industry abnormal returns are not positive and statistically significant as reported in Appendix C are treated as regular years as if no deregulation events occurred. To address the potential impacts of the deregulation years with negative and statistically significant industry abnormal returns, this study excludes those firm-year observations from the analysis as a robustness check. Specifically, the baseline model is re-estimated for the highly levered high-growth and low-growth firms, excluding observations for firms of the affected industries during those deregulation years.

Appendix G reports the results. For the high-growth firms, the coefficients of the interaction of debt maturity and the deregulation indicator remain positive and statistically significant. For the low-growth firms, the coefficients remain statistically insignificant. Overall, the shorter maturity effect on investment response to deregulation is significantly more positive in the high-growth firms, as revealed by the coefficients of the triple interaction of debt maturity, the deregulation indicator, and the high-growth indicator. This alternative analysis produces no significant change to the main result that shorter debt maturity alleviated debt overhang.

To further examine if the effect of debt maturity on investment response to deregulation is associated with debt overhang, this study re-runs the baseline model using low-leverage firms as a counterfactual test. The results are reported in Panel A of Appendix H. The coefficients of the interaction of debt maturity and the deregulation indicator are statistically insignificant in both the high-growth and low-growth firms with low leverage. Firms with low leverage are less likely to suffer from debt overhang and the evidence reveals no significant effect of debt maturity on investment response to deregulation by those firms.

In Panel B of Appendix H, this study directly compares all high-growth firms against low-growth firms. The coefficients of the interaction of debt maturity and the deregulation indicator are positive and statistically significant in high-growth firms. In contrast, coefficients of the interaction term are not statistically significant in low-growth firms. Coefficients of the triple interaction reveal a statistically significant difference in the debt maturity effects between high-growth and low-growth firms.

The results reveal that shorter debt maturity has a positive and significant effect on change in investment in response to deregulation only in high-growth firms; no such effect is observed in low-growth firms. The evidence indicates that the positive effect of shorter debt maturity on investment response to deregulation is likely associated with the attenuation of debt overhang. This is consistent with the idea that shorter debt maturity alleviates debt overhang.

5.3. Adverse business conditions and the maturity-investment relation

Diamond and He (2014) suggests that shorter debt maturity can exacerbate debt overhang, particularly when business conditions deteriorate and the costs of rolling over debt increase. To examine this hypothesis, this study re-estimates the baseline model for firms that face adverse

business conditions and firms that face favorable business conditions, using several alternative firm-level measures of business conditions. One such measure relies on the probability of default from the Merton model. This study partitions the highly levered high-growth firms into subsamples of firms facing adverse conditions (the default probability above the 75th percentile) and firms facing favorable conditions (the default probability below the 75th percentile).[5] If shorter debt maturity is associated with stronger overhang in the firms facing adverse conditions, the relation between shorter debt maturity and investment response to deregulation should turn negative. In contrast, for the firms facing favorable conditions in which costs of shorter maturity are likely to remain low and outweighed by the benefit of alleviating debt overhang, the relation should remain positive.

The results are reported in Appendix I. For firms facing favorable conditions, the coefficients of the interaction of debt maturity and the deregulation indicator are 0.062 for the three-year debt maturity measure and 0.046 for the five-year maturity measure, both positive and statistically significant at the 0.05 level. For firms facing adverse conditions, coefficients of the interaction are statistically insignificant. Using shorter-maturity indicator. The results reveal that investment response to deregulation of firms facing favorable conditions with shorter debt maturity is significantly greater than that of counterpart firms with longer debt maturity. Firms facing adverse conditions exhibit no such dependence of the investment response to deregulation on the maturity of their debt.

[5] The sample median default probability is approximately zero so the 75th percentile is used as the cutoff to more accurately group the firms by business conditions.

To provide formal tests of the differential debt maturity effect between firms facing adverse and favorable conditions, this study uses a triple interaction of debt maturity, the deregulation indicator, and an indicator for firms facing favorable conditions. The coefficients of the triple interaction are statistically insignificant for the three-year and five-year debt maturity measures. The results confirm the findings that shorter debt maturity has a positive effect on investment response to deregulation in firms facing favorable conditions and the effect is not reversed to negative in firms facing adverse conditions.

This study uses two additional firm-level measures of business conditions, 1) Altman's Z-score (Altman, 1968), and 2) the inverse of Altman's Z-score constructed by Kim, Mauer, and Sherman (1998). The results, which are not tabulated for brevity, are similar to the main results of the study.

Overall, the evidence indicates that shorter debt maturity is not associated with a weaker investment response to deregulation, even in firms facing adverse conditions. There is no evidence that shorter debt maturity increases debt overhang in those firms or, for that matter, in other firms that are examined. Furthermore, the evidence from firms facing favorable conditions reinforces the earlier conclusion that shorter debt maturity alleviates debt overhang.

6. Alternative interpretations and robustness of the results

6.1. Market states and the maturity-investment relation

Shorter debt maturity can increase debt overhang not only when firm-specific conditions deteriorate, but when market-wide conditions deteriorate (He and Xiong, 2012). During such market conditions, both borrowers and lenders (investors) could experience deteriorated business conditions, leading to a general increase in the costs of rolling over debt. In this

subsection, this study employs an alternative, market-wide measure of business conditions to split the sample years. It examines whether the effect of debt maturity on investment response to deregulation is market-state dependent. If shorter debt maturity increases debt overhang during low state of the market, a negative relation between shorter debt maturity and investment response to deregulation should be expected at those market times.

This study identifies market states based on annual stock market returns and separately based on the classification of economic expansions and recessions by the National Bureau of Economic Research (NBER). Years with negative stock market returns are low markets and the other years are high markets. Stock market returns are measured by the annual returns on the S&P 500 (Standard and Poor's 500) index. The alternative CRSP value-weighted index produces the same classification of years. Alternatively, years of NBER recessions are low markets and the other years are high markets.

This study estimates the baseline model for highly levered high-growth firms during high markets and during low markets. The results are reported in Appendix J. During high markets, the coefficients of the interaction of debt maturity and the deregulation indicator are all positive and statistically significant. During low markets, none of the coefficients on the interaction is statistically significant. The coefficients of the triple interaction of debt maturity, deregulation indicator, and the indicator for high markets estimating the differential debt maturity effect between high and low markets are statistically insignificant. During high markets, shorter-maturity firms increase their investment more or underinvest less in response to deregulation than longer-maturity firms. This reveals the evidence that shorter debt maturity alleviates debt

overhang during high markets. There is no evidence that shorter debt maturity increases debt overhang even during low markets.

The evidence indicates that the otherwise positive effect of shorter debt maturity on investment response to deregulation becomes insignificant when firms face adverse business conditions or during low markets. One possibility is that the costs associated with shorter debt maturity are greater in such conditions. However, these costs appear no greater than those of longer debt maturity suggested by Myers (1977). Another possibility is that firms in such conditions do not respond to shocks to investment opportunities regardless of debt maturity. Regardless of the reason, this study finds no support for the notion that shorter debt maturity exacerbates debt overhang or longer debt maturity alleviates overhang.

6.2. Robustness checks of prior effects of debt maturity and asset maturity effects

It is possible that industries that undergo or are about to undergo deregulation are systematically different from other industries, including in characteristics such as debt maturity and investment. If so, it is possible that debt maturity in years leading up to deregulation is related to investment as well. This study performs a placebo test by testing the relation between debt maturity and change in investment in years prior to deregulation, introducing artificial shocks in prior years and examining if the relation documented during deregulation is also observed in those years.

This study supplements the baseline model with two additional indicator variables (Preshock1 and Preshock2) which indicate for calendar years one year prior and two years prior to the deregulation year. It also includes interactions of debt maturity with these indicators into the model. The interactions capture the debt maturity effects on change in investment during

the years prior to deregulation. The study estimates the expanded model for highly levered high-growth firms and firms facing favorable business conditions, as these are samples in which the strongest relation between debt maturity and investment response is observed.

The results are reported in Columns (1)-(2) and (5)-(6) of Appendix K. The coefficients of the interactions in years prior to deregulation are all statistically insignificant. In contrast, the coefficients of interactions in deregulation years all remain positive and statistically significant. In the full sample of highly levered high-growth firms, the coefficients of the interaction of debt maturity and deregulation indicator are 0.054 and 0.048 for the three-year and five-year debt maturity measures, positive and statistically significant at the 0.05 and 0.01 levels, respectively. For firms facing favorable conditions, the coefficients are 0.069 and 0.050 for three-year and five-year debt maturity measures, respectively, both positive and statistically significant at the 0.05 level. The positive and significant relation between shorter debt maturity and investment response is confined to deregulation years, and does not manifest in years leading up to deregulation.[6]

The next test is motivated by Myers's (1977) argument that firms can match the maturity of their assets and the maturity of their debt to reduce the potential underinvestment problems caused by debt overhang. Accordingly, the relation between debt maturity and debt overhang may depend on asset maturity. As such, this study includes asset maturity as a control variable in the baseline model and verify if the positive effect of shorter debt maturity on investment response to deregulation holds. Following Stohs and Mauer (1996) and Johnson (2003), asset

[6] Alternatively, this study performs the expanded model without the deregulation indicator and its interaction with debt maturity. The results are similar that there is no significant debt maturity effect in the years prior to deregulation.

maturity is the weighted sum of the maturity of long-term assets and the maturity of current assets.

The results are reported in columns (3)-(4) and (7)-(8) of Appendix K. For highly levered high-growth firms, the coefficients on the interaction term of debt maturity and deregulation indicator are 0.052 for the three-year debt maturity measure and 0.043 for the five-year debt maturity measure, both positive and statistically significant at the 0.05 level. For firms facing favorable conditions, the coefficients on the interaction term are 0.073 for the three-year debt maturity measure and 0.045 for the five-year debt maturity measure, positive and statistically significant at the 0.05 and 0.10 levels, respectively. As a further robustness check, this study includes the interaction of asset maturity and deregulation indicator in the baseline model in addition to controlling for asset maturity. The coefficients on the interaction of debt maturity and deregulation indictor remain positive and statistically significant. Altogether, the results of the study are robust to potential asset maturity effects.

7. Debt maturity and investment response to natural gas prices

In this section, this study focuses the analysis on the natural gas producers and uses high price of natural gas as an exogenous shock to their investment opportunities. Gilje and Taillard (2016) argue that investment opportunities of natural gas producers are affected by natural gas prices. The profitability of new investment of natural gas producers is directly tied to natural gas prices; higher prices represent more valuable investment opportunities to the gas producers.[7]

[7] Future gas price uncertainties may prevent gas producers from fully capturing the benefits of current high gas price. In practice, they hedge the price risk by locking in prices for future deliveries, which are highly positively correlated with the spot price (Gilje and Taillard 2016). This enables their investment in a high-price year to fully capture the benefits of high price.

This study investigates how debt maturity affects natural gas producers' investment in high gas price environments. If shorter debt maturity alleviates debt overhang, a positive relation between shorter debt maturity and investment in response to high gas prices should be expected for gas producers susceptible to debt overhang.

Focusing on natural gas producers, this study restricts the sample to firms with SIC codes between 1311 and 1389. Following Gilje and Taillard (2016), it measures natural gas price by the annual U.S. wellhead price, which is available on the website of U.S. Energy Information Administration (EIA). Since 2012 is the last year with available natural gas wellhead price, the sample period is extended to 2012. The exogenous shock variable is now the indicator for years of high gas prices (High price). This study defines the sample years when natural gas prices are in the top tercile as years of high gas prices or high gas price environments. The dependent variable is the level of net investment in this test because unlike the deregulation shock which is concentrated in time, the period of high gas prices can last several years. It follows Gilje and Taillard (2016) that high-price years represent the price environments with greater investment opportunities to gas producers, and using the investment level allows for direct comparison of investment in high-price years and the other years. Control variables are those from the baseline model. Additionally, one-year lagged net investment is included to control for the differences in baseline investment. The key variable of interest is the interaction of debt maturity and the high-price indicator, which measures the effect of shorter debt maturity on gas producers' investment in high gas price environments relative to the other periods.

The model is estimated for highly levered high-growth and low-growth gas producers and the results are reported in Appendix L. The coefficients on the interaction of continuous debt

maturity measures and the high-price indicator are positive but statistically insignificant for the high-growth sample. When debt maturity is measured by the indicator of shorter debt maturity, the coefficients on the interaction of debt maturity and the high-price indicator are positive and statistically significant for the high-growth sample and statistically insignificant for the low-growth sample. The triple interaction coefficients estimating the differential effect between the high-growth and low-growth samples are positive and statistically significant when debt maturity is measured using the shorter-maturity indicator. Removing the control of year effects from the model generates similar results.

Overall, there is evidence that shorter debt maturity is positively associated with investment of the gas producers likely to face debt overhang in high gas price environments relative to other periods. The evidence offers further support to hypothesis that shorter debt maturity alleviates debt overhang.

8. Conclusions and discussion

Using industry deregulation and alternatively high prices of natural gas as the exogenous positive shock to investment opportunities, this study examines how the *ex-ante* variation in debt maturity is related to firms' investment response. To examine whether the results represent the effects of debt overhang, this study focuses on firms that have valuable investment opportunities and high leverage where debt overhang is more likely to exist. The evidence is consistent with the hypothesis that debt of shorter maturity alleviates debt overhang by encouraging more investment in response to increased investment opportunities.

This study provides direct empirical evidence, using an exogenous positive shock to investment opportunities, on the role of debt maturity in investment distortions associated with

debt overhang.[8] The evidence reveals a positive and significant effect of shorter debt maturity on the incentive to pursue valuable investment opportunities only in firms most likely subject to debt overhang. As such, the evidence contributes to the empirical studies that document adverse effects of debt overhang. By providing direct empirical evidence that shorter debt maturity alleviates debt overhang, this study helps to explain the existing empirical findings why firms with valuable investment opportunities shorten debt maturity.

The empirical evidence is also relevant to the existing studies debating on the benefits and costs of shorter debt maturity. This study considers the argument that shorter debt maturity can exacerbate debt overhang particularly for firms facing adverse business conditions or during low markets. The evidence in this study indicates that shorter debt maturity does not increase debt overhang in such conditions. Shorter debt maturity does appear to reduce underinvestment associated with debt overhang particularly in firms facing favorable business conditions or during high markets. This evidence helps explain the reasons as to why firms would shorten debt maturity given the potential costs. The evidence points to a value of shorter debt maturity to firms with valuable investment opportunities but a large amount of debt that distorts the investment incentives.

[8] A few other studies examine the relation between debt maturity and investment for a broad sample of Compustat firms across all sample years. For example, Aivazian, Ge, and Qiu (2005) document a positive relation between shorter debt maturity and investment, which is stronger for high-growth firms. In contrast, Hong, Hou, and Nguyen (2023) find this relation to be negative. Different from those studies, this study exploits an exogenous positive shock to investment opportunities and the likely predetermined maturity structure of long-term debt in an effort to pin down a causal maturity effect on firm investment response right during the shock.

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Appendix A: Variable definitions and construction

This appendix provides the variable definitions and construction of the common variables used in the study. All variables in uppercase letters refer to the Compustat items.

Variable Name	Definition
Altman's Z-score	1.2*[(RECT + INVT - AP)/AT] + 1.4*(RE/AT) + 3.3*[(IB + DP)/AT] + 0.6*[(PRCC*CSHO)/(DLTT + DLC)] + (SALE/AT).
Asset maturity	The weighted sum of the maturity of long-term assets and the maturity of current assets, where the maturity of long-term assets is gross property, plant, and equipment divided by depreciation expense (PPEGT/DP), the maturity of current assets is current assets divided by the costs of goods sold (ACT/COGS), the weight for long-term assets is gross property, plant, and equipment divided by the book value of total assets (PPEGT/AT), and the weight for current assets is current assets divided by the book value of total assets (ACT/AT).
Boom	Indicator variable equal to one for years of positive annual stock market returns, and zero otherwise.
Expansion	Indicator variable equal to one for NBER expansion years, and zero otherwise.
Fav_con	Indicator variable equal to one for firms where Merton's probability of default is below the 75th percentile, and zero otherwise.
Firm size	The natural logarithm of the book value of total assets (AT).
High price	Indicator variable equal to one for years of high natural gas prices, years when the annual U.S. wellhead prices are in the highest tercile during the sample period, and zero otherwise.
High Q	Indicator variable equal to one for firms of market-to-book ratios greater than one, and zero otherwise.
Industry abnormal return	Average abnormal return across all sample firms in the industry, where firm abnormal returns are estimated as firm actual returns minus the benchmark Fama and French 25 size and book-to-market portfolio returns.
Inverse Z-score	1/{1.4*(RE/AT) + 3.3*[(IB + DP)/AT] + 0.6*[(PRCC*CSHO)/(DLTT + DLC)] + (SALE/AT)}.

Variable Name	Definition
Investment	Net capital expenditure scaled by lagged total assets, (CAPX - DP)/AT.
Leverage	Market leverage, the book value of total debt divided by the market value of total assets, (DLTT + DLC)/(AT - CEQ + PRCC*CSHO).
Market-to-book ratio	Q, market value of total assets divided by book value of total assets, (AT - CEQ + PRCC*CSHO)/AT.
Maturity_3yr	The book value of long-term debt maturing withing three years divided by the book value of total debt, (DD1 + DD2 + DD3)/(DLTT + DLC).
Maturity_5yr	The book value of long-term debt maturing withing five years divided by the book value of total debt, (DD1 + DD2 + DD3 + DD4 + DD5)/(DLTT + DLC).
Preshock1	Indicator variable equal to one for the calendar year one year before the year of deregulation shock, and zero otherwise.
Preshock2	Indicator variable equal to one for the calendar year two years before the year of deregulation shock, and zero otherwise.
Sales growth	The growth rate of sales (SALE).
Shock	Indicator variable equal to one for the calendar year when a deregulation shock occurred in the firm's primary industry defined by the 4-digit SIC code, and zero otherwise.
Smat_3yr	Indicator variable equal to one for firms where the ratio of book value of long-term debt maturing within three years to book value of total debt is above the sample median, and zero otherwise.
Smat_5yr	Indicator variable equal to one for firms where the ratio of book value of long-term debt maturing within five years to book value of total debt is above the sample median, and zero otherwise.
Tangibility	Net property, plant, and equipment scaled by the book value of total assets, PPENT/AT.

Appendix B: Summary Statistics

This appendix provides the summary statistics of the main variables related to the analysis of this study. The sample period is from 1977 to 2006. The sample consists of industries including entertainment, petroleum and natural gas, telecommunications, and transportation. Level of investment is net capital expenditure (capital expenditure net of depreciation and amortization) divided by lagged total assets. Change in investment is the one-year change in net capital expenditure divided by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Market leverage is book value of total debt divided by book value of total assets plus market value of equity less book value of equity.

	Mean	Stdev	25%	Median	75%
Level of investment	0.055	0.080	0.003	0.038	0.085
Change in investment	0.004	0.046	-0.021	0.001	0.025
Maturity_3yr	0.185	0.202	0.036	0.117	0.264
Maturity_5yr	0.300	0.269	0.075	0.228	0.464
Market leverage	0.314	0.172	0.179	0.310	0.439

Appendix C: Industry abnormal returns around major sample deregulations

This appendix provides the estimated annual abnormal return of the affected industry for each major sample deregulation year. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level based on t-statistics in the parentheses.

Panel A: Petroleum & Natural gas, and Telecommunications

Industry	Deregulation year	Annual abnormal return
Petroleum and Natural Gas	1978	-15.51%***
		(-5.32)
Petroleum and Natural Gas	1981	-20.19%***
		(-6.97)
Petroleum and Natural Gas	1989	14.49%***
		(3.28)
Petroleum and Natural Gas	1992	0.88%
		(0.20)
Telecommunications	1979	33.20%**
		(2.51)
Telecommunications	1980	0.38%
		(0.03)
Telecommunications	1981	41.07%**
		(2.42)
Telecommunications	1982	12.43%
		(0.89)
Telecommunications	1984	25.80%
		(1.19)
Telecommunications	1988	6.82%
		(0.88)
Telecommunications	1996	-19.89%***
		(-3.40)

Panel B: Transportation and Entertainment

Industry	Deregulation year	Annual abnormal return
Transportation	1978	-6.27%
		(-0.90)
Transportation	1980	-3.97%
		(-0.32)
Transportation	1982	-4.56%
		(-0.52)
Transportation	1984	0.89%
		(0.10)
Transportation	1986	-13.12%*
		(-1.96)
Transportation	1987	0.13%
		(0.01)
Transportation	1993	32.90%**
		(2.50)
Transportation	1994	-9.54%
		(-1.43)
Transportation	1995	-15.85%***
		(-2.79)
Entertainment	1980	-17.30%
		(-1.30)
Entertainment	1981	20.80%
		(1.02)
Entertainment	1984	-3.30%
		(-0.37)

Appendix D: Univariate test for the effect of debt maturity on change in investment

This appendix provides the univariate test results for the effect of debt maturity on change in investment of highly levered high-growth firms during deregulation and non-deregulation years. Numbers in the table are mean and median one-year changes in net capital expenditure scaled by lagged total assets. The firms are partitioned by debt maturity at the sample median into shorter-maturity and longer-maturity firms. Debt maturity is measured by the ratio of book value of long-term debt maturing within three or five years to book value of total debt (Maturity_3yr or Maturity_5yr). Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level based on t-statistics in the parentheses.

	Deregulation years				Non-deregulation years				Difference			
	Maturity_3yr		Maturity_5yr		Maturity_3yr		Maturity_5yr		Maturity_3yr		Maturity_5yr	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Shorter-maturity firms	0.017	0.014	0.019	0.014	0.005	0.002	0.005	0.002	0.012**	0.012**	0.014***	0.012***
									(2.27)	(2.38)	(2.84)	(2.60)
Longer-maturity firms	0.004	0.002	0.001	0.000	0.005	0.002	0.005	0.002	-0.001	-0.000	-0.004	-0.002
									(-0.15)	(-0.06)	(-0.84)	(-0.33)
Difference	0.013*	0.012*	0.018***	0.014**	0.000	-0.000	0.000	0.000	0.013*	0.012*	0.018***	0.014**
	(1.94)	(1.92)	(2.73)	(2.18)	(0.28)	(-0.01)	(0.23)	(0.12)	(1.86)	(1.89)	(2.64)	(2.12)

Appendix E: Effect of debt maturity on change in investment of highly levered firms

This appendix provides the results of baseline model for highly levered high-growth firms in columns (1)-(4) and highly levered low-growth firms in columns (5)-(8). The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Smat_3yr and Smat_5yr are indicators for shorter-maturity firms where the three-year and five-year maturity ratios are above sample median, respectively. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	High growth				Low growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.049**				-0.027			
	(2.20)				(-0.78)			
Maturity_5yr x Shock		0.045***				-0.021		
		(2.60)				(-0.92)		
Smat_3yr x Shock			0.018**				-0.008	
			(2.03)				(-0.70)	
Smat_5yr x Shock				0.023***				-0.002
				(2.83)				(-0.17)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,207	5,207	5,207	5,207	2,545	2,545	2,545	2,545
Adjusted R-squared	0.0768	0.0768	0.0773	0.0776	0.0868	0.0842	0.0827	0.0829

Appendix F: Differential effect between highly levered high-growth & low-growth firms

This appendix provides the results of expanded baseline model for highly levered firms. The expanded model incorporates the triple interaction of debt maturity, the deregulation shock indicator (Shock), and the indicator for high-growth firms (High Q). The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Smat_3yr and Smat_5yr are indicators for shorter-maturity firms where the three-year and five-year maturity ratios are above sample median, respectively. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)
Maturity_3yr x Shock x High Q	0.070*			
	(1.91)			
Maturity_5yr x Shock x High Q		0.063**		
		(2.46)		
Smat_3yr x Shock x High Q			0.021*	
			(1.66)	
Smat_5yr x Shock x High Q				0.026**
				(2.06)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	7,752	7,752	7,752	7,752
Adjusted R-squared	0.0740	0.0736	0.0740	0.0741

Appendix G: Deregulations with significant negative industry abnormal returns

This appendix provides the results of baseline model for highly levered high-growth and low-growth firms excluding observations for firms of the industries during deregulation years with negative and statistically significant industry abnormal returns as reported in Appendix C. The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Smat_3yr and Smat_5yr are indicators for shorter-maturity firms where the three-year and five-year maturity ratios are above sample median, respectively. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	High growth				Low growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.048**				-0.020			
	(2.11)				(-0.54)			
Maturity_5yr x Shock		0.044**				-0.014		
		(2.53)				(-0.57)		
Smat_3yr x Shock			0.018**				-0.003	
			(2.07)				(-0.30)	
Smat_5yr x Shock				0.024***				0.003
				(2.85)				(0.25)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,899	4,899	4,899	4,899	2,295	2,295	2,295	2,295
Adjusted R-squared	0.0809	0.0815	0.0809	0.0818	0.1013	0.0976	0.1004	0.0980
High growth – Low growth:								
Maturity_3yr x Shock x High Q		0.065*		Smat_3yr x Shock x High Q			0.019	
		(1.73)					(1.49)	
Maturity_5yr x Shock x High Q		0.059**		Smat_5yr x Shock x High Q			0.024*	
		(2.27)					(1.93)	

Appendix H: Maturity effect of other samples and its association with debt overhang

This appendix provides the results of baseline model for high-growth and low-growth firms with low leverage in Panel A, and for all high-growth and low-growth firms in Panel B. The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Smat_3yr and Smat_5yr are indicators for shorter-maturity firms where the three-year and five-year maturity ratios are above sample median, respectively. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

Panel A: Low leverage

	High growth				Low growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.043				0.109			
	(1.23)				(1.34)			
Maturity_5yr x Shock		0.028				0.113		
		(1.06)				(1.04)		
Smat_3yr x Shock			0.021				0.059	
			(1.45)				(0.96)	
Smat_5yr x Shock				0.019				0.085
				(1.26)				(0.98)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,993	1,993	1,993	1,993	178	178	178	178
Adjusted R-squared	0.0930	0.0935	0.0931	0.0927	0.2092	0.1965	0.2012	0.2065

Panel B: All high growth and low growth

	High growth				Low growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.042**				-0.029			
	(2.57)				(-1.12)			
Maturity_5yr x Shock		0.038***				-0.023		
		(2.84)				(-1.18)		
Smat_3yr x Shock			0.017**				-0.009	
			(2.43)				(-0.84)	
Smat_5yr x Shock				0.022***				-0.004
				(3.23)				(-0.42)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,200	7,200	7,200	7,200	2,723	2,723	2,723	2,723
Adjusted R-squared	0.0786	0.0786	0.0789	0.0791	0.0808	0.0773	0.0771	0.0764
High growth – Low growth:								
Maturity_3yr x Shock x High Q	0.067**		Smat_3yr x Shock x High Q			0.021*		
	(2.31)					(1.82)		
Maturity_5yr x Shock x High Q	0.056***		Smat_5yr x Shock x High Q			0.026**		
	(2.61)					(2.29)		

Appendix I: Effect of business conditions on the maturity-investment relation

This appendix provides the results of baseline model for subsamples of highly levered high-growth firms partitioned on firm-specific business conditions. Columns (1)-(2) report results for firms facing favorable business conditions where Merton's probability of default is below the 75th percentile, and columns (5)-(8) report results for firms facing adverse business conditions where Merton's probability of default is above the 75th percentile. The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	Favorable conditions		Adverse conditions	
	(1)	(2)	(3)	(4)
Maturity_3yr x Shock	0.062**		-0.004	
	(2.27)		(-0.08)	
Maturity_5yr x Shock		0.046**		0.006
		(2.16)		(0.16)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	3,373	3,373	949	949
Adjusted R-squared	0.0649	0.0645	0.1413	0.1380
Favorable conditions – Adverse conditions:				
Maturity_3yr x Shock x Fav_con	-0.013			
	(-0.23)			
Maturity_5yr x Shock x Fav_con	-0.042			
	(-0.78)			

Appendix J: Effect of market states on the maturity-investment relation

This appendix provides the results of baseline model for highly levered high-growth firms in high market-state and low market-state years. Columns (1)-(2) and (5)-(6) report results using annual stock market return as a proxy for market states, and columns (3)-(4) and (7)-(8) report results using NBER classification of economic expansion and recession as a proxy for market states. The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	High market states				Low market states			
	Boom stock market		NBER expansion		Bust stock market		NBER recession	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.050**		0.042*		-0.063		-0.074	
	(2.04)		(1.74)		(-0.41)		(-1.01)	
Maturity_5yr x Shock		0.045**		0.041**		-0.036		-0.043
		(2.30)		(2.14)		(-0.44)		(-0.94)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,080	4,080	4,330	4,330	1,127	1,127	877	877
Adjusted R-squared	0.0694	0.0695	0.0662	0.0664	0.0838	0.0847	0.1221	0.1206
Boom – Bust:			Expansion – Recession:					
Maturity_3yr x Shock x Boom	-0.074		Maturity_3yr x Shock x Expansion				0.008	
	(-0.96)						(0.12)	
Maturity_5yr x Shock x Boom	-0.026		Maturity_5yr x Shock x Expansion				0.010	
	(-0.58)						(0.25)	

Appendix K: Robustness tests for asset maturity and lagged debt maturity effects

This appendix provides the results of expanded baseline models for highly levered high-growth firms in columns (1) to (4), and the subsample of firms facing favorable business conditions in columns (5) to (8). Columns (1)-(2) and (5)-(6) report results of the baseline model including two pre-deregulation year indicators (Preshock1 and Preshock2) and their interactions with debt maturity. Columns (3)-(4) and (7)-(8) report results of the baseline model including asset maturity as the additional control variable. The dependent variable is one-year change in net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Shock is the deregulation shock indicator. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	High growth				Favorable conditions			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x Shock	0.054**		0.052**		0.069**		0.073**	
	(2.43)		(2.05)		(2.47)		(2.50)	
Maturity_5yr x Shock		0.048***		0.043**		0.050**		0.045*
		(2.80)		(1.99)		(2.30)		(1.91)
Maturity_3yr x Preshock1	0.026				0.008			
	(1.13)				(0.27)			
Maturity_5yr x Preshock1		0.016				-0.004		
		(0.93)				(0.17)		
Maturity_3yr x Preshock2	0.037				0.006			
	(1.18)				(0.15)			
Maturity_5yr x Preshock2		0.027				0.018		
		(0.97)				(0.59)		
Control for asset maturity			Yes	Yes			Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,207	5,207	4,200	4,200	3,373	3,373	3,126	3,126
Adjusted R-squared	0.0775	0.0786	0.0864	0.0864	0.0653	0.0651	0.0686	0.0676

Appendix L: Effect of debt maturity on investment response to natural gas prices

This appendix provides the test results for differences in investment of natural gas producers that differ in debt maturities in high and low natural gas price environments. Columns (1)-(4) report results for highly levered high-growth firms and columns (5)-(8) report results for counterpart low-growth firms. The dependent variable is the level of investment measured by net capital expenditure scaled by lagged total assets. Maturity_3yr is the ratio of book value of long-term debt maturing within three years to book value of total debt. Maturity_5yr is the ratio of book value of long-term debt maturing within five years to book value of total debt. Smat_3yr and Smat_5yr are indicators for shorter-maturity firms where the three-year and five-year maturity ratios are above sample median, respectively. High price is the indicator for high gas price environments. Firm fixed and year effects are controlled. *t* statistics for the significance of the coefficients are in parentheses. The standard errors of the coefficients are adjusted for clustering of observations at the firm level. Statistical significance is denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.

	High growth				Low growth			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Maturity_3yr x High price	0.097				0.138*			
	(1.50)				(1.75)			
Maturity_5yr x High price		0.058				0.040		
		(1.28)				(0.68)		
Smat_3yr x High price			0.051***				0.029	
			(2.98)				(1.01)	
Smat_5yr x High price				0.035**				-0.021
				(2.09)				(-0.83)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	794	794	794	794	250	250	250	250
Adjusted R-squared	0.3674	0.3738	0.3733	0.3729	0.2247	0.2253	0.2128	0.2275
High growth – Low growth:								
Maturity_3yr x High price x High Q	-0.003			Smat_3yr x High price x High Q		0.044*		
	(-0.04)					(1.72)		
Maturity_5yr x High price x High Q	0.026			Smat_5yr x High price x High Q		0.044*		
	(0.37)					(1.67)		