# Construction, Systematic Risk, and Stock-Level Investment Anomalies*

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**Abstract**

We offer evidence that the tendency of high real-investment stocks to underperform others ("investment anomaly") is almost entirely attributable to firms physically constructing new capacity. The conditioning ability of construction work does not come from constructing firms making larger investments, relying on other financing sources, or being differentially profitable over or after the investment year. Yet, it may arise from their profits becoming less sensitive to their industries' conditions after that year. Setting up a real options model of the firm in which newly-built capacity becomes operational only after a time-to-build period but ultimately produces profits which are less sensitive to negative demand shocks over some random time, we show that our evidence is consistent with neoclassical finance theory.

Key words: Asset pricing; real options; investment anomalies; flexible capacity; time-to-build.

JEL classification: G11, G12, G15.

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# 1 Introduction

A large empirical literature suggests that high real-investment stocks tend to produce lower future returns than other stocks, with the gap, however, closing over a small number of years after the investment year ("investment anomaly"). See, for example, Titman et al. (2004), Anderson and Garcia-Feijóo (2006), Fama and French (2006; 2008), Cooper et al. (2008), Xing (2008), and Cooper and Priestley (2011). Motivated by these findings, modern factor models often include an investment factor long low-investment and short high-investment stocks to successfully explain the cross-section of stock returns. See, for example, Hou et al.'s (2015) $q$-theory model and Fama and French's (2015, 2016) five-factor model.

We offer new evidence that the investment anomaly is almost entirely attributable to firms physically building new capacity ("constructing firms"), with it, however, also disappearing within that subset of firms after about three to five years. Further tests suggest that the reason for constructing firms to drive the anomaly is unrelated to their investment intensity, financing sources, profitability, and asset or market size over or after the investment period. Yet, the reason may be related to the finding that the profits of constructing firms become less sensitive to their industries' conditions after the same period, perhaps due to newly-built capacity being more flexible than more mature acquired capacity. Setting up a real options model of the firm in which newly-built capacity becomes operational only with some time-to-build gap, but produces profits which are less sensitive to negative demand shocks for some while, we finally demonstrate that our evidence can be reconciled with neoclassical finance theory.

In the first part of our study, we condition the performance of the investment anomaly on construction work. To do so, we measure investments as the (scaled) change in gross property, plant, and equipment (PPE) over the fiscal year ending in calendar year $t-1$, consistent with us being most interested in real investments into physical productive capacity. Focussing on the sample period over which we can measure construction (1986-2016), we first confirm that our investment variable and that sample period produce an investment anomaly. We next use the “property, plant, and equipment construction-in-progress” (PPE-CIP) account to identify those firms for which construction work is at least partially behind their investments. In line with U.S. accounting rules, the PPE-CIP account gathers all construction-related expenses over the construction period. Seperately studying firms with positive and zero PPE-CIP balances at the end of the investment period, we show that the investment anomaly is highly significant for constructing firms but usually insignificant for others. Our portfolio sorts, for example, suggest that the spread portfolio long the highest value-weighted investment decile and short the lowest yields a mean return of –12.35% per annum ($t$-statistic: –3.21) in the constructing-stock subsample, but of only –3.95% ($t$-statistic: –1.31) in the other. Similarly, our FM regressions suggest that moving from the lowest to the highest PPE-CIP-to-total assets rank decreases the investment premium by a striking 2.17% per month ($t$-statistic: –3.14).

Our conclusions survive independent of whether we (i) exclude missing PPE-CIP values or set them to zero; (ii) condition based on PPE-CIP values from the last one or two fiscal years; (iii) include or exclude service firms; (iv) impose alternative sales and price screens; and (v) use levered or artificially delevered returns in our tests. They further hold for several other popular investment proxies, such as Titman et al.’s (2004) abnormal CAPEX; Xing’s (2008) scaled CAPEX; Cooper et al.’s (2008) assets growth; as well as Peters and Taylor’s (2017) capital growth. In line with intuition, they are, however, statistically and economically stronger for proxies more closely reflecting real investments into physical productive capacity.

In the second part of our study, we search for reasons for why constructing firms appear to be behind the investment anomaly. In doing so, we start with comparing high-investment constructing firms with other high-investment firms along several dimensions. The comparisons suggest that constructing firms increase their productive capacity to a similar extent as the other firms. They further suggest that both types of firms finance their investments through issuing similar amounts of equity and debt capital. Also interestingly, the constructing and non-constructing firms are close to equally profitable over the investment period and the five years proceeding it, refuting the idea that the low post-investment returns of constructing firms are caused by those firms' construction projects going over budget.[1] The comparisons finally indicate that the two types of firms are of a similar market and book size and share close to equally attractive growth opportunities, as measured using book-to-market ratios.

We next contrast industry sensitivity across constructing firms and others, running panel regressions of a firm's profit growth on its industry's output-price growth, an interaction between the industry variable and a dummy variable indicating whether a firm engaged in construction in the recent past, control variables, and fixed effects. The regressions reveal that constructing firms become significantly less sensitive to their industries over the about five years after construction, but that the lower sensitivity disappears again after that period. Also, the lower sensitivity comes almost exclusively from industry recession states. An explanation for those findings may be that newly-built capacity is better able to react to negative shocks to industry demand than more mature capacity, perhaps due to it being more operationally flexible and easy to reconfigure. While Milgrom and Roberts (1990) and Upton (1995) advise that capacity flexibility is the linchpin to corporate survival in recent times, Tolio (2009) stresses that firms significantly differ in the types of flexibility optimally required by them. Given that constructing firms build new capacity from scratch, they may be more able to endow their capacity with those types of flexibility most suitable to them. Even those types of flexibility are, however, likely to be short-lived due to continuous changes in technology, demands, etc.

In the final part of our study, we develop a real options model of a firm which is able to buy or build new capacity to demonstrate that neoclassical finance theory is consistent with our evidence. Similar to Carlson et al.'s (2004), Cooper's (2006), Hackbarth and Johnson's (2015), and Aretz and Pope's (2018) models, ours also considers a monopolistic firm producing and instantaneously selling an output good at a stochastic price. To do so, the firm optimally decides, in each instant, how much to produce ("production decision") and whether to install

[1] We are indebted to Michael Brennan for this alternative explanation of our findings.

more capacity ("investment decision"). To distinguish between buying and building capacity, we next add two novel features to our model. Consistent with Kydland and Prescott (1982) and Carlson et al. (2010), we first assume that building implies that newly-built capacity becomes operational only after some construction time ("time-to-build"). Consistent with our evidence, we further assume that newly-built capacity generates gross profits which are less sensitive to negative demand shocks until the capacity ages. To incorporate the second assumption in a simple way, we impose a lower bound on the gross profits generated by newly-built capacity, with the lower bound, however, disappearing with some fixed probability per instant.

Calculating the effect of investment on the expected firm return from a calibration of the model, the model confirms that only capacity builders (but not buyers) observe an investment-induced decline in their expected returns, with the decline, however, reverting over a small number of years. The reason is that the value of newly-built capacity is less sensitive to negative demand shocks than the value of mature capacity, lowering the systematic risk of capacity builders. As the newly-built capacity, however, ages, its sensitivity to negative demand shocks increases, closing the expected return gap between builders and buyers again.

We add to a large empirical literature analyzing stock-level investment anomalies, including the studies cited at the start of the introduction. While behavioral studies in that literature generally claim that the anomaly arises due to investors only slowly realizing that managers often invest into value-destroying projects (see Jensen (1986) and Titman et al. (2004)), neoclassical studies attribute the anomaly to investing firms transforming high-risk growth options into low-risk assets-in-place (see Myers (1977) and Carlson et al. (2006)). Of those two explanations, the behavioral explanation has an edge since only it is consistent with the anomaly disappearing a small number of years after the investment year. Moreover, despite its intuitive appeal, the neoclassical explanation requires further assumptions, such as an upper bound on the number of growth options held by firms, to induce investment to lower the expected firm return (see Carlson et al. (2004, 2006, 2010)). Since larger firms are, however, likely to be closer to that bound, models with limits to growth predict the investment anomaly to be stronger among larger firms, conflicting with the evidence of Fama and French (2008).[2] Our work contributes to those studies by offering a new neoclassical real options based explanation for the investment anomaly which is more consistent with our new but also the existing evidence.

We further add to a literature developing theoretical models of the firm featuring time-to-build and flexible capacity. Majd and Pindyck (1987) and Pindyck (1993) look into a firm optimally deciding on the progress it makes on a construction project, imposing an upper limit on that progress to ensure a positive time-to-build. Different from them, we assume that, once a firm has started construction work, it can neither alter its pace nor abandon it, in line with the results of Koeva (2000).[3] Conversely, Fine and Freud (1990) study a firm in a two-period setting with independent multiple-product demands, deriving the investments into flexible and inflexible capacity maximizing expected profitability. Triantis and Hodder (1990) value fixed quantities of flexible and inflexible capacity in a multi-period model with dependent demands. Finally, He and Pindyck (1992) determine optimal investment policies for and the valuation of flexible capacity in a continuous-time model. Our modelling of newly-built capacity can be seen as the special case of He and Pindyck (1992) in which capacity can be reconfigured to produce an alternative output good with a fixed sales price over some period.

We structure our paper as follows. Section 2 shows that only constructing firms produce an economically and statistically significant investment anomaly. Section 3 searches for reasons

[2]Sagi and Seasholes (2007) shed more light on why real-options investment models require limits to growth to induce investment to lower the expected firm return. More specifically, they point out that, in such models, investment is triggered by a positive demand (or productivity) shock. Viewed in isolation, the shock skews a firm's value away from its low-risk assets-in-place and toward its high-risk growth options and thus increases the expected firm return ("rebalancing effect"). The investment in turn implies that the firm converts some of its high-risk growth options into lower-risk assets-in-place, decreasing the expected firm return again ("investment effect"). Since the strength of the rebalancing (investment) effect crucially depends (does not depend) on the number of growth options still available to the firm, we can render the effect of investment on the expected firm return more negative by imposing a tighter upper bound on the number of growth options.

[3]Koeva (2000) finds that about 90% of her sample construction projects were completed on time and that only one project was ultimately abandoned. She argues that costly penalties imposed on firms for delaying construction work explain her results. In accordance with her results, Lamont (2000) shows that firms' ex-ante investment plans explain about three-quarters of their ex-post variations in investment outlays, suggesting that managers hardly ever adjust their original investment plans in response to economic news.

for why constructing firms appear to be behind the anomaly. In Section 4, we develop a real options model of a firm which can either buy or build new capacity, demonstrating that the model is consistent with our evidence. Section 5 sums up and concludes our paper.

# 2 Construction and the Pricing of Investment

In this section, we show that the investment anomaly is almost entirely driven by the subsample of firms physically building new capacity. To do so, we first introduce our analysis variables and data sources, giving more details about the variables in Table A.1 in the appendix. We next confirm that our variables and sample period produce an investment anomaly. More importantly, we then condition the anomaly on construction work. We finally run several robustness tests using alternative model specifications and investment proxies.

## 2.1 Variables and Data Sources

We first define our analysis variables and outline our data sources. Since we are most interested in investments into physical productive capacity, we measure firm-level investment as the change in gross PPE over the fiscal year ending in calendar year $t-1$ scaled by total assets at the start of that fiscal year, using the calculated value from June of calendar year $t$ to May of calendar year $t+1$ (*Investment*). Different from CAPEX-based proxies, as, for example, Titman et al.'s (2004) abnormal CAPEX or Xing's (2008) CAPEX-to-PPE, our proxy also captures physical capacity expansions facilitated through acquisitions. Different from broader proxies, as, for example, Cooper et al.'s (2008) assets growth, our proxy, however, excludes investments into assets not adding to future profitability, such as cash and accounts receivables (see Peters and Taylor (2017)). Notwithstanding these differences, we later show that our main conclusions also broadly hold for popular alternative investment proxies.

We make use of a firm's PPE-CIP account balance (Compustat item: fatc) at the end of the investment period to gauge whether the firm raises its capacity through physically building new capacity. As mandated by U.S. accounting rules, the PPE-CIP account collects all expenses a firm incurs in the construction of an asset over the construction period, with examples of such expenses being material costs, vendor invoices, and transportation outlays. Once construction is finished, the account balance is then transferred into the relevant fixed-PPE account (often "buildings" or "machinery and equipment"). Since firms with a positive PPE-CIP balance at the end of the investment period thus have outstanding construction work, we often simply choose those firms as our "constructing firms." To be more granular, we alternatively, however, also sometimes condition on construction intensity, defined as the PPE-CIP balance at the end of the investment period scaled by total assets at its start (*Construction*).

We concede that the PPE-CIP account allows us to only imperfectly measure whether a firm's investments are facilitated through it physically building new capacity. While capacity-under-construction raises both gross PPE (and thus *Investment*) and PPE-CIP, we only observe the PPE-CIP balance at the end of the fiscal year. The upshot is that we cannot correctly identify smaller capacity expansions arising from construction work taking place within the confines of a single fiscal year.[4] A further complication is that there could be time mismatches, with, for example, the PPE-CIP balance at the current fiscal year end reflecting gross PPE increases which took place over earlier years. Despite those issues, we are optimistic that PPE-CIP allows us to identify those firms building large amounts of their new capacity.

We use a standard set of control variables in our tests. In our portfolio sorts, we adjust for the Hou et al. (2015) $q$-theory or the Fama and French (2015) five-factor model factors. In our FM regressions, we control for *MarketBeta*, *MarketSize*, *BookToMarket*, *Momentum*, and *Profitability*. We compute *MarketBeta* as the slope coefficient from a time-series regression of a stock's daily return on the daily market return over the prior twelve months, setting the

[4] Relatedly, our main approach to identify constructing firms also fails to correctly identify those which start construction before the fiscal year over which investment is measured but finish it within that year. To address that shortcoming, we later run a robustness test in which we define constructing firms to be those with a positive PPE-CIP balance either at the start and/or the end of the investment year.

variable to missing if the regression is run on fewer than 200 observations. *MarketSize* is the log of the product of common shares outstanding and the share price in month $t-1$. We calculate *BookToMarket* as the log ratio of the book value of equity from the fiscal year ending in calendar year $t-1$ to the market value of equity from the end of calendar year $t-1$, using the calculated value from June of calendar year $t$ to May of calendar year $t+1$. *Momentum* is the stock return compounded over months $t-12$ to $t-2$. We calculate *Profitability* as sales minus costs of goods sold (COGS), selling, general, and administrative (SG&A) expenses, and interest expenses scaled by total assets from the fiscal year ending in calendar year $t-1$, using the calculated value over the same period over which we use *BookToMarket*. See Table A.1 in the appendix for more details about the calculations of the control variables.

We obtain market data from CRSP, accounting data from Compustat, and the benchmark factor data from Kenneth French and Lu Zhang. We study the common stocks (share codes: 10 and 11) of firms traded on the NYSE, AMEX, and Nasdaq. To make sure that our sample firms use at least some physical assets in their operations, we exclude firms from the financial (SIC codes: 6000–6999), utilities (4900–4949), and services (7000–8999) industries.[5] To focus on comparing investing and non-investing firms, we also drop firms with negative *Investment* values (i.e., disinvesting firms). To guard against microstructure-induced confounding effects, we eliminate firms with a market capitalization below the first quintile in June of calendar year $t$ and/or sales below $25 million in the fiscal year ending in calendar year $t-1$ from the July of year $t$ to June of year $t+1$ sample period. To mitigate backfilling biases, we discard the current data of stocks included in Compustat for fewer than two years.

We follow Shumway (1997) and Bali et al. (2017) in dealing with stock exchange delistings, setting a stock's return to its CRSP delisting return whenever the latter is available. Whenever the delisting return is unavailable, we set the stock return to –30% for delisting codes 500, 520,

[5]While it is common to exclude financial and utility firms from asset pricing tests in the literature, our choice to also exclude service firms is less common. We exclude service firms since we believe that investments into physical capacity, as reflected by *Investment*, are presumably of an only secondary importance for such firms. Despite that, we later show that retaining service firms does not greatly change our conclusions.

551–573, 574, 580, or 584 and −100% for all others. With the exception of the stock return, we winsorize our analysis variables at the 0.5th and 99.5th percentiles calculated per month. We set missing PPE-CIP values to zero in our main tests, but later conduct a robustness test in which we exclude missing PPE-CIP observations.[6] Due to the availability of the PPE-CIP data, our sample period is July 1986 to December 2016 (366 monthly observations).

## 2.2 Descriptive Statistics and Correlations

Table 1 offers descriptive statistics (Panel A) and Pearson correlations (Panel B) for *Investment*, *Construction*, and a dummy variable equal to one if *Construction* is positive and else zero (*ConstructionIndicator*). We calculate the descriptive statistics and the correlations first by sample month and then average over our sample period. Panel A suggests that the mean (median) sample firm raises its productive capacity by close to nine (five) percent of its total assets per year (see column (1)). Of that increase, about 13% (zero percent) can be attributed to the firm physically building new capacity (see column (2)). That estimate is, however, a lower bound since, as we discussed, we cannot correctly identify construction work started and finished within the same fiscal year. Overall, column (3) indicates that close to 40% of our sample firms have ongoing construction work in the average sample month.

The average standard deviation, skewness, kurtosis, and percentile statistics in Panel A suggest that *Investment* and *Construction* display great dispersions. While close to three-quarters of our sample firms only mildly raise their physical productive capacity by no more than 10% of their assets, the remainder raises it by an average of almost 25%, consistent with evidence that firm-level investment occurs in "spikes" (see, e.g., Doms and Dunne (1998) and Cooper and Haltiwanger (2006)). Conversely, of the about 40% constructing firms in the average sample month, around 60% have an only small fraction of their assets under construction below 2.5%,

[6] Interestingly, the fraction of firms not reporting their PPE-CIP balances is only significant (around 20% of our sample) until the early 1990s. Consistent with a global push toward more PPE transparency, as, for example, reflected in 1993's IAS 16 stating that firms "should also disclose [. . .] the amount of expenditures on account of property, plant and equipment in the course of construction," the fraction drops below 10% after then.

while the remainder produces a much higher average fraction of close to 5%.

Panel B indicates that *Investment* and *Construction* share a significantly positive average correlation of 0.19, suggesting that construction work explains a meaningful fraction of firms' investment activities. Neither of the two variables is, however, strongly related to our control variables. The exception is the 0.11 correlation between *Construction* (or *ConstructionIndicator*) and *MarketSize*, indicating that larger firms are more likely to build capacity.

## 2.3 The Pricing of *Investment*

We next turn to univariate portfolio sorts to confirm that *Investment* produces an investment anomaly over our sample period. At the end of each June in our sample period, we thus sort our sample firms into portfolios according to the tenth, 50th, and 90th percentiles of the *Investment* distribution on the same date, focusing on these percentiles to contrast high versus close-to-zero investment firms. We also form a spread portfolio long the highest and short the lowest *Investment* portfolio ("LS90-10"). We value or equally-weight the portfolios and hold them from start of July of year $t$ to end of June of year $t+1$. We risk-adjust portfolio returns by regressing them on either the Hou et al. (2015) $q$-theory or the Fama-French (2015) five-factor-model factors and reporting the intercept ("alpha"). In either case, we, however, exclude the model's investment factor (titled "INV" or "CMA") from those regressions since its inclusion would explain the investment anomaly almost by construction.

Table 2 gives the results from the univariate portfolio sorts, offering the annualized mean excess returns and alphas of the portfolios (in %) as well as several portfolio characteristics including the average number of stocks and the average cross-sectional means of *Investment* and *Construction* over our sample period (as plain numbers). The table further shows the $t$-statistics for the mean excess returns and alphas of the spread portfolios calculated using Newey and West's (1987) formula with a six-month lag length (in square brackets). Panels A and B focus on the value-weighted and equally-weighted portfolios, respectively.

The table confirms that *Investment* is significantly negatively priced in both the value and equally-weighted portfolios. Looking at the value-weighted portfolios in Panel A, column (4) suggests that mean excess returns decline from 9.67% per month for the lowest *Investment* decile to 3.82% for the highest. The spread in those numbers is a significant –5.84% ($t$-statistic: –2.18). Turning to the equally-weighted portfolios in Panel B, we find an even stronger negative relation, with mean excess returns now declining from 11.37% for the lowest *Investment* decile to 3.94% for the highest. Given that, the spread in those numbers is an even more significant –7.43% ($t$-statistic: –2.99). Adjusting the mean excess returns of the spread portfolios for the $q$-theory or five-factor-model factors in, respectively, columns (5) and (6) reveals that the models' non-investment-based factors cannot explain the investment anomaly.

The portfolio characteristics suggest that, while the bottom-*Investment*-decile firms hardly raise their productive capacity at all, the top-decile firms raise theirs by a striking 50% of their assets on average (see column (2)). In line with intuition, they also suggest that higher *Investment*-value firms have more assets under construction. To be specific, column (3) suggests, while the bottom-*Investment*-decile firms have fewer than one percent of their assets under construction, the same number is between 2.50% and 5.50% for the top-decile firms. Column (1) finally suggests that all value and equally-weighted portfolios are well-diversified.

## 2.4 Conditioning the Pricing of *Investment* on *Construction*

We now study whether the investment anomaly depends on whether investing firms physically build new capacity. At the end of each June in our sample period, we thus again sort firms into portfolios according to the tenth, 50th, and 90th percentiles of the *Investment* distribution on the same date. We next sort the same firms into portfolios according to whether they have a positive or zero *Construction* value on that date. We finally create double-sorted portfolios from the intersection of the two univariate sorts. Within each *Construction* portfolio, we form a spread portfolio long the highest and short the lowest *Investment* portfolio ("LS90-10"). We again value- or equally-weight the portfolios and hold them from July of year $t$ to June of year $t+1$. To risk-adjust portfolio returns, we again regress them on either the $q$-theory or five-factor-model factors excluding the models' investment-based factors.

Table 3 offers the results from the value- (Panel A) and equally-weighted (Panel B) double portfolio sorts, giving the same statistics as Table 2 separately for positive (Panels A.1 and B.1; "constructing firms") and zero (Panels A.2 and B.2) *Construction*-value stocks. The table strongly suggests that the investment anomaly is attributable to constructing firms. To be more specific, column (4) suggests that, while the value- (equally-) weighted spread portfolio formed from constructing firms attracts a highly significant mean excess return of –12.35% (–11.99%) per annum ($t$-statistic: –3.21 (–5.28)), the corresponding spread portfolio formed from other firms attracts an only insignificant mean excess return of –3.95% (–5.39%). Adjusting the mean spread portfolio returns for the $q$-theory or five-factor-model factors in, respectively, columns (5) and (6) does not alter those conclusions. Columns (2) and (3) finally show that a large fraction of the investments of constructing firms come through construction work, with the equally-weighted mean of *Construction* (9.32), for example, making up almost 25% of the equally-weighted mean of *Investment* (38.19) for the top investment-decile firms (see Panel B).[7]

While the double portfolio sorts suggest that the investment anomaly is only *statistically* significant in the constructing-firm subsample, we next study whether the conditioning effect of construction work on the anomaly is also economically important. To that end, Figure 1 plots the cumulative returns of value- (Panel A) and equally-weighted (Panel B) spread portfolios long the *lowest* investment-decile stocks and short the *highest* over our sample period, using either the full sample, the constructing-firm subsample, or the non-constructing-firm subsample to form the spread portfolios.[8] The figure vividly demonstrates that the spread portfolio formed

[7]Rather surprisingly, the lowest investment-decile firms in Panels A and B produce a higher mean *Construction* value than mean *Investment* value. Since new PPE-CIP expenses necessarily increase gross PPE, the reason for that result must be that the lowest investment-decile firms have incurred a large fraction of the expenses in their PPE-CIP accounts before the start of the period over which we measure investment.

[8]We interchange the two legs of the investment spread portfolios in Figure 1 to make sure that the spread portfolios produce positive (and not negative) returns on average.

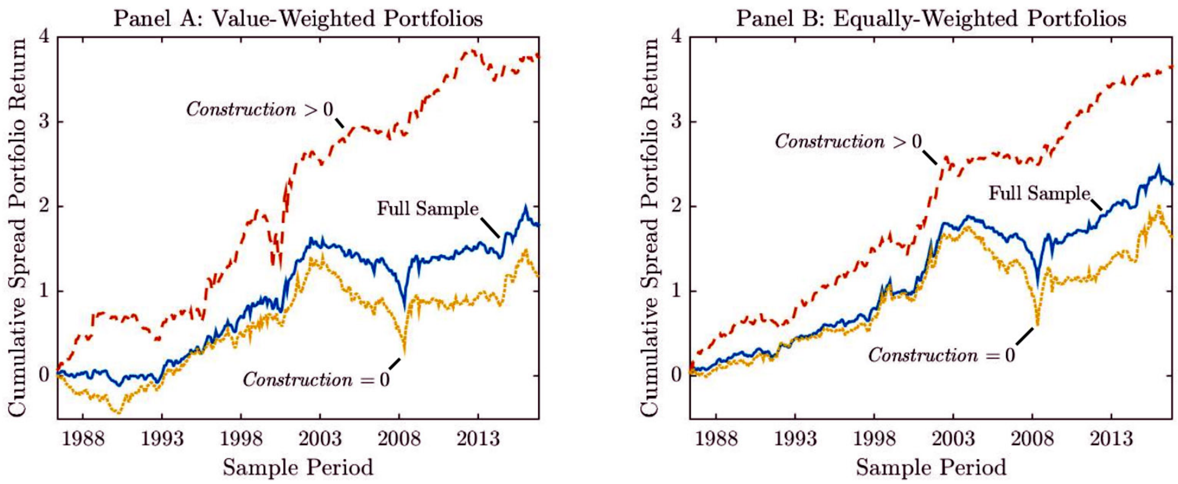


**Figure 1: The Cumulative Returns of Investment Spread Portfolios Formed from Constructing and Non-Constructing Firms** In this figure, we plot the cumulative returns of value- (Panel A) and equally-weighted (Panel B) spread portfolios long the bottom *Investment*-decile stocks and short the top decile stocks over our sample period. The spread portfolios are formed from either all firms (solid blue line), constructing firms (dashed red line), or non-constructing firms (dotted yellow line).

from constructing firms is far more profitable than the spread portfolios formed from all or non-constructing firms. The value-weighted constructing-firm spread portfolio in Panel A, for example, earns a close to \$4 excess payoff over our sample period, while the excess payoff of the corresponding non-constructing-firm spread portfolio only slightly exceeds \$1.

In Table 4, we switch to FM regressions to examine how construction work conditions the investment anomaly, first, to establish that our portfolio sort results are robust to changes in methodology and, second, to also use more granular conditioning variables. In column (1), we project the single-stock return over month $t$ on *Investment* and our control variables measured until the end of month $t-1$ to confirm that the FM regressions support the existence of an investment anomaly in stock data. In columns (2) and (3), we then also include an interaction between *Investment* and either *Construction* or a rank variable based on *Construction* plus the construction variable on its own. While the interaction with *Construction* directly conditions the investment anomaly on the magnitude of construction work, the interaction with the rank variable based on *Construction* achieves the same without allowing outlier *Construction* values to distort regression results. In columns (4) and (5), we finally repeat the regression in column

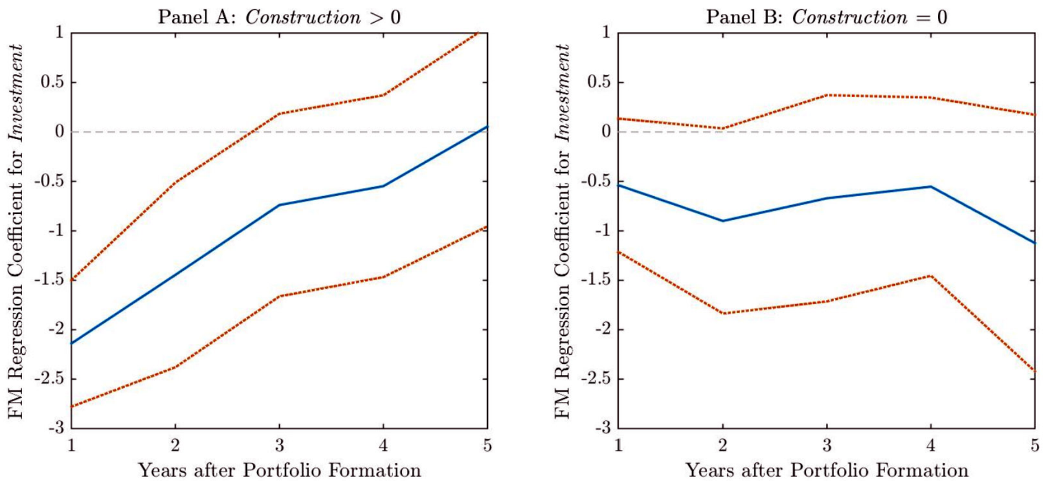


**Figure 2: The *Investment* Premium Over the Post-Investment Period** In this figure, we plot the *Investment* premium from FM regressions of single-stock returns over month $t + x$ on *Investment* and control variables measured until the end of month $t - 1$, running the regressions separately on firms with a positive (Panel A) and zero (Panel B) *Construction* value. We set $x$ equal to zero, twelve, 24, 36, and 48. Solid lines are monthly *Investment* premium estimates (in %), while dotted lines are 95% confidence bands calculated from Newey and West's (1987) formula with a lag length equal to six months.

(1) separately on the positive and zero *Construction*-value firm subsamples, reporting the difference in estimates across the subsamples in column (4)–(5). Plain numbers are monthly premium estimates (in %), while the numbers in square brackets are $t$-statistics calculated using Newey and West's (1987) formula with a lag length equal to six months.

The FM regressions yield results in complete agreement with those derived from the portfolio sorts. In particular, column (1) indicates that the *Investment* premium is equal to –1.01% per month ($t$-statistic: –3.17) even when controlling for *MarketBeta*, *MarketSize*, *BookToMarket*, *Momentum*, and *Profitability*. Columns (2) to (3), however, reveal that the premium depends crucially on whether firms physically build their new capacity. Column (3), for example, suggests that raising *Construction* from its first quartile to its third decreases the premium by slightly more than one percent per month ($t$-statistic: –3.14). In accordance, the subsample regressions in columns (4) and (5) show that the investment premium is a highly significant –2.14% per month ($t$-statistic: –6.58) for constructing firms but an only insignificant –0.54% ($t$-statistic: –1.57) for others. The difference is a highly significant –1.60% ($t$-statistic: –3.94).

Given that prior studies suggest that the investment anomaly vanishes a small number of years after the investment year, we finish this section by exploring whether it does so too in the constructing-firm subsample. To do so, we repeat the FM regressions on the constructing-firm and non-constructing-firm subsamples in, respectively, columns (4) and (5) of Table 4, this time, however, leading the stock return on the left-hand side by zero, twelve, 24, 36, or 48 months relative to before. We show the *Investment* premiums obtained from those regressions in Figure 2, with Panels A and B focusing on the constructing-firm and non-constructing-firm subsample regressions, respectively. The figure shows that the investment anomaly also disappears in the constructing-firm subsample over a period of about three years, while it is never significant over a single year within that same period in the non-constructing-firm subsample.

## 2.5 Robustness Tests

We next study whether our evidence that constructing firms are behind the investment anomaly is driven by methodological choices we make in our main tests. Table 5 thus presents the results from the full-sample FM regression in column (1) and the subsample regressions on constructing and non-constructing firms in, respectively, columns (4) and (5) of Table 4, this time, however, making alternative choices. In column (1), we exclude observations with missing PPE-CIP values rather than setting those to zero (see footnote 6). In column (2), we define a constructing firm to have a positive PPE-CIP balance either at the start or the end of the investment period (see footnote 4). Column (3) retains service firms (see footnote 5). While in column (4) we retain firms with sales below $25 million in the fiscal year ending in the prior calendar year, column (5) excludes firms with a stock price below $5 at the end of June of the current year rather than those with a market capitalization below the first quartile on the same date. In column (6), we finally use artificially delevered returns rather than standard returns on the left-hand side of the regressions to control for financial leverage effects.[9] For the sake of

[9]We follow Doshi et al. (2019) in computing the delevered stock return as a stock's standard return multiplied by one minus its financial leverage. We define financial leverage as the ratio of total liabilities to

brevity, the table only reports *Investment* premium estimates and the differences in these across the two subsamples. As before, plain numbers are monthly estimates (in %), while numbers in square brackets are Newey-West (1987) $t$-statistics with a six-month lag length.

The table suggests that our methodological choices do not drive our conclusions. While the first row of the table reveals that the *Investment* premium is significantly negative in the full sample under all alternative choices, the second and third rows show that the same premium is 2-5 times more negative and, with one exception, only significant in the constructing-firm but not in the non-constructing-firm subsample. The last row suggests that the difference in the *Investment* premium across the two subsamples is always highly significant.

## 2.6 Alternative Investment Proxies

We finally explore whether we can also conclude that constructing firms drive the investment anomaly when we rely on alternative investment proxies. Doing so is important since other studies often use alternative proxies, raising the question whether our findings have implications for them. To that end, Table 6 presents the results from the same FM regressions as in Table 5, this time, however, using our main proxy, Xing's (2008) CAPEX-to-PPE, Titman et al.'s (2004) abnormal CAPEX-to-sales, Peters and Taylor's (2017) capital growth, and Cooper et al.'s (2008) assets growth as investment proxy in columns (1) to (5), respectively.[10] While in contrast to our main proxy the CAPEX proxies do not consider expansions of physical productive capacity arising through M&As, the capital growth (assets growth) proxy additionally considers expansions of intangible productive capacity (all other assets). To be consistent with the studies proposing those investment proxies, we do not exclude service firms from the regressions in Table 6, yet else impose the same restrictions as in our main empirical tests.

the sum of market capitalization and total liabilities, where total liabilities is from the fiscal year ending in the prior calendar year and market capitalization from the end of the prior calendar year. We use the calculated value from June of the current calendar year to May of the next calendar year.

[10]See Table A.1 in Appendix A for the definitions of the alternative investment proxies.

The table suggests that the investment anomaly is consistently stronger in the constructing-firm subsample than in the non-constructing-firm subsample for all investment proxies. Despite that, the *Investment* premium difference across those subsamples is generally more pronounced for proxies more closely reflecting investments into physical productive capacity. While the difference is, for example, a highly significant –1.06% and –0.62% per month ($t$-statistics: −2.54 and –2.43) for our main proxy and CAPEX-to-PPE in columns (1) and (2), it is a slightly less significant –0.32% and –0.21% ($t$-statistics: –2.05 and –1.70) for capital growth and assets growth in columns (4) and (5), all respectively. Conversely, the difference is insignificant for abnormal CAPEX-to-sales. Our results thus confirm that the conditioning effects of construction work are stronger for investments tilted toward physical productive capacity, in line with construction work being only able to produce such types of capacity. Notwithstanding, the conditioning effects exist, albeit more weakly, also for alternative investment proxies.

Taken together, this section offers strong evidence that the investment anomaly is almost exclusively driven by the subsample of firms physically building new capacity, as suggested by value- and equally-weighted double portfolio sorts, FM regressions featuring interactions between investment and construction work, and subsample FM regressions separately run on constructing and non-constructing firms. The evidence is robust to various methodological choices and also holds, albeit sometimes more weakly, for popular alternative investment proxies. Notwithstanding, the investment anomaly also disappears in the constructing-firm subsample over the about three-year period after the investment year.

# 3 What Can Explain the Conditioning Effect of *Construction* for the Pricing of *Investment*?

In this section, we search for reasons for why constructing firms are behind the investment anomaly. To do so, we first contrast high-investment constructing and non-constructing firms across several important firm characteristics, including investment, equity and debt issuances, profitability, market and book size, and book-to-market, both over and after the investment year. We next also compare the sensitivity of their operating profits to the demand conditions of the industries to which they belong before and after the investment period.

## 3.1 A Comparison of Firm Fundamentals

Table 7 contrasts the mean values of a number of firm characteristics across high-investment constructing and non-constructing firms over the investment year as well as the next five years, defining a high-investment firm to be a firm with an *Investment* value within the top decile over the investment year. To facilitate comparisons, the table relies on only firms also included in our portfolio sorts and FM regressions in Section 2, but further excludes those for which we cannot calculate a firm characteristic's value for all six years by firm characteristic. We compute means first by investment year and then average over our sample period. We finally also calculate the change in a mean from the investment year to five years later (column "5–0") and the difference in a mean across constructing and non-constructing firms (row "(1)–(2)"). Plain numbers are mean estimates or the differences in them, while numbers in square brackets are $t$-statistics calculated from Newey and West's (1987) formula with a six-month lag length.

The firm characteristics studied in the table are investment, equity financing, debt financing, profitability, market size, total assets, and book-to-market. While investment and profitability are identical to *Investment* and *Profitability*, market size and book-to-market are the non-logged counterparts of *MarketSize* and *BookToMarket*, all respectively. Following Cooper et al. (2008), we calculate equity financing as the change in common equity plus preferred stock plus minority interests minus retained earnings over a fiscal year, while we calculate debt financing as the change in debt in current liabilities over the same fiscal year, both scaled by total assets at the start of that year. Market size and total assets are both measured in billion $.

We select the above firm characteristics for the following reasons. We contrast the scale of the investments made by constructing and non-constructing firms to find out whether our conclusions can be explained by constructing firms making significantly larger investments than non-constructing firms.[11] We look into whether the two types of firms use different financing sources since other studies suggest that firms often prefer equity financing when their stock is overvalued (e.g., Rau and Vermaelen (1998) and Agrawal and Jaffe (2000)). Thus, if constructing firms tend to rely more strongly on equity financing than non-constructing firms, their low post-investment returns could simply be a correction of stock mispricing. We study whether there are differences in profitability for two separate reasons. First, since newly-built assets are presumably more modern and technologically advanced than mature assets, they may incur lower operating costs, opening up the possibility that a decline in operating leverage after construction drives the low post-investment returns of constructing firms (e.g., Carlson et al. (2004) and Cooper (2006)). Second, the low returns may also be explained by investors only slowly realizing that construction projects often go over budget over time. We look into market and book size since other studies show that the investment anomaly is stronger for smaller firms (see Fama and French (2008)). We finally compare book-to-market ratios to see whether the two types of firms differ in terms of the growth options available to them.

Table 7 offers little support for the hypotheses outlined above. Panel A suggests that, if anything, constructing firms invest slightly less than non-constructing firms, with the difference, however, only being statistically but not economically significant. Conversely, Panels B and C show that, while both types of firms raise equity capital and, to a smaller extent, debt capital to finance their investments, they do not differ in the magnitude of their issuances. Over the investment year, constructing firms, for example, raise their equity capital by 10.48% on average, while non-constructing firms raise it by 10.51%. The difference in those numbers is a highly insignificant –0.03% ($t$-statistic: –0.02). As shown in Panel D, we further fail to find significant

[11] While the independent double portfolio sorts in Section 2.4 ensure that investment intensity is similar across high-investment constructing and non-constructing firms, the high positive skewness of *Investment* (as shown in Panel A of Table 1) may imply that the portfolio sorts do so only imperfectly.

differences in profitability, either across the two types of firms or over time. That constructing firms do not become more or less profitable over time does not align with the hypotheses that either operating leverage and/or unbudgeted construction costs explain their post-investment returns. Although Panels E and F suggest that constructing firms are slightly smaller than non-constructing firms, the differences are statistically and economically small. Panel G finally shows that the two types of firms have similar book-to-market ratios, indicating that growth opportunities account for about the same proportion of their firm values.

## 3.2 Comparing Industry Sensitivities

We next contrast the sensitivity of a firm's profits to the demand conditions of the industry in which the firm operates across constructing and non-constructing firms. As argued in Milgrom and Roberts (1990), Upton (1995), and Tolio (2009), firms increasingly focus on the flexibility embedded in their production capacity to survive in ever more uncertain markets, characterized by frequent changes in demand, technology, and competition. Flexible capacity can, however, differ with respect to its, for example, product mix and volume, new products, input materials and handling, and routing flexibility, with the optimal amounts of specific forms of flexibility strongly varying across firms (Koste and Malhotra (1999)). Since constructing firms build new capacity from scratch, it is conceivable that they are more able than other firms to endow their new capacity with those flexibility forms required by them, making them less dependent on their industry's demand conditions once the newly-built capacity is in place.

We use panel regressions to compare industry sensitivities across constructing and non-constructing firms before, after, and longer after the investment period. To be more specific, we estimate the following regression on firm-quarter data:

$$
\begin{aligned}
ProfitGrowth_{i,k,t} &= \beta IndustryPriceGrowth_{k,t} + \gamma Construction^{q,w}_{i,k,t} \\
&+ \delta(IndustryPriceGrowth_{k,t} \times Construction^{q,w}_{i,k,t}) \\
&+ \eta' Controls_{i,k,t} + \alpha_i + \alpha_t + \epsilon_{i,k,t}, \qquad (1)
\end{aligned}
$$

where *ProfitGrowth* is the change in the difference between firm $i$'s quarterly sales (Compustat item: saleq) and costs of goods sold (cogsq) from calendar quarter $t-1$ to $t$ scaled by total assets at the start of the quarter ("operating profitability"), *IndustryPriceGrowth* is the change in the average-output-good price of industry $k$ over that same period, $Construction^{q,w}$ is a dummy equal to one if firm $i$ engaged in construction work over the period from year $q$ to $w$, and *Controls* is a vector of control variables. $\alpha_i$ and $\alpha_t$ are firm and time fixed effect, $\beta$, $\gamma$, and $\delta$ are parameters, $\eta$ is a vector of parameters, and $\epsilon$ is the residual. We interpret a firm with construction work over the recent past as a firm with newly-built assets-in-place.

We calculate *IndustryPriceGrowth* using Chang and Hwang's (2015) industry classification scheme, first aggregating firm sales (saleq) at the industry level to obtain each industry's sales growth from calendar quarter $t-1$ to $t$.[12] To avoid spurious results, we however compute industry sales growth separately by firm, with the value for firm $i$ excluding the sales of that firm. We next retrieve data on the quarterly total output growth for each industry.[13] We finally back out *IndustryPriceGrowth* from the following accounting identity:

$$
IndustrySalesGrowth_{k,t} = IndustryPriceGrowth_{k,t} \times IndustryQuantityGrowth_{k,t}, \qquad (2)
$$

where *IndustrySalesGrowth* is the sales growth of industry $k$ from quarter $t-1$ to $t$ and

[12] While Chang and Hwang (2015) define 74 industries, we only use those with more than ten firms in every sample quarter, leaving us with the 32 industries shown in Table A.3 of the appendix.

[13] We obtain those data from the Federal Reserve's industrial production and capacity utilization database.

*IndustryQuantityGrowth* is its output quantity growth over the same period.[14] Assuming that Chang and Hwang's (2015) industries are reasonably competitive, *IndustryPriceGrowth* captures shocks to the demand for the output produced by the firms in industry $k$.[15]

In line with Novy-Marx (2013), we use the following controls. *LagProfitGrowth* is one-quarter lagged *ProfitGrowth*. *QuarterlyReturn* is the stock return over the current quarter. *Momentum* is the one-year stock return until the end of the prior quarter. *MarketSize* is log market size at the end of the prior quarter. *BookToMarket* is the log ratio of book equity from the fiscal year end before the end of the prior quarter to market size at the end of that quarter.[16]

Table 7 reports the regression results. In column (1), we set $Construction^{q,w}$ to one if the firm has a positive PPE-CIP balance in at least one of the *following* five years and else zero ("pre-construction period"). Conversely, in columns (2) to (4), we set $Construction^{q,w}$ to one if the firm has a positive balance in at least one of the *previous* five years and else zero ("post-construction period"). While column (2) considers the full-sample regression, columns (3) and (4) focus on the subsample regressions run on only observations for which *IndustryPriceGrowth* over the past two years is above and below the full-sample median, respectively. Finally, columns (5) and (6) repeat the subsample regressions in, respectively, columns (3) and (4), this time, however, defining $Construction^{q,w}$ based on the five-year period ending five years before the current date. To be comparable with our asset pricing results, we only include firm-quarter observations if the firm was included in our portfolio sorts and FM regressions in Section 2 over the prior five years. Plain numbers are parameter estimates, while the numbers in square

[14] We can write firm $i$'s sales over quarter $t$, *Sales*, as its output quantity, *Quantity*, multiplied by its output price, *Price*, over that quarter. Summing that identity over all firms in industry $k$, we obtain: $\sum_{i=1}^{N} Sales_{i,k,t} = \sum_{i=1}^{N}(Quantity_{i,k,t} \times Price_{i,k,t})$, where $N$ is the number of firms in that industry. Multiplying and dividing the right-hand side by the total output produced by the $N$ firms in that quarter, we obtain: $\sum_{i=1}^{N} Sales_{i,k,t} = \sum_{i=1}^{N} Quantity_{i,k,t} \times \left(\sum_{i=1}^{N} \frac{Quantity_{i,k,t}}{\sum_{i=1}^{N} Quantity_{i,k,t}} \times Price_{i,k,t}\right)$. Dividing the last equality by the corresponding equality for quarter $t-1$, we derive the accounting identity shown in Equation (2).

[15] In calculating *ProfitGrowth* and *IndustryPriceGrowth*, we assume that, when a firm's fiscal quarters do not correspond to calendar quarters, quarterly sales and quarterly costs of goods sold are evenly distributed over the three underlying months, whereas total assets are the same at the end of each of those months.

[16] We winsorize each continuous variable used in the regressions at the first and last percentile computed per quarter (including the variables underlying the interactions but excluding the interactions).

parentheses are $t$-statistics calculated from White (1980) standard errors.

The table suggests that constructing firms observe a decline in their industry sensitivities after the construction work is finished, with that decline, however, reverting over time. To be specific, column (1) reveals that constructing and non-constructing firms are significantly positively sensitive to their industries before the construction work, with the difference in their sensitivities, however, being insignificant (see the coefficient and $t$-statistic on the interaction between *IndustryPriceGrowth* and $Construction^{q,w}$). Shortly after construction, the sensitivities of the constructing firms are, however, 0.23 ($t$-statistic: –3.45) lower than those of the non-constructing firms, as demonstrated by column (2). Interestingly, columns (3) and (4) show that the lower sensitivities of constructing firms originate from industry recession states, with the coefficient on the interaction between *IndustryPriceGrowth* and $Construction^{q,w}$ only being significant in the low past *IndustryPriceGrowth* subsample ($t$-statistic: –3.86) and not in the other subsample ($t$-statistic: –1.13). Finally, the lower sensitivities of constructing firms revert back to the sensitivities of non-constructing firms over time, with the interaction coefficients in columns (5) and (6) no longer being significant in the high or low past *IndustryPriceGrowth* subsamples. The control coefficients align with those in Novy-Marx (2013).

Overall, this section suggests that constructing and non-constructing firms do not differ along important firm fundamentals, including investment intensity, financing sources, profitability, size, and growth opportunities. Conversely, the two types of firms differ in terms of their industry sensitivities, with constructing firms being less sensitive to their industries' conditions than non-construction firms for some years after the construction work.

# 4 A Real Options Model of the Firm in Which the Firm Can Buy or Build Additional Capacity

In this section, we introduce a real options model of a firm in which the firm can buy or build new capacity to find out whether our evidence in Sections 2 and 3 can be successfully tied together within a standard neoclassical setup. While it appears obvious that the lower sensitivity of newly-built capacity to negative demand shocks lowers the systematic risk of constructing firms in such a setup, other differences between constructing and non-constructing firms (as, e.g., the time it takes to build new capacity) could dominate or offset the sensitivity effect. We start with laying out the model's assumptions. We next present its solution. We finally conduct a calibration exercise contrasting the short-term and long-term effects of investment on the expected firm return across constructing and non-constructing firms.

## 4.1 Model Assumptions

In our model, we study a monopolistic all-equity-financed firm operating in continuous time indexed by $t \in \{0, +\infty\}$. To maximize its value, the firm decides, in each instant, on how much of a homogenous output good to produce and instantaneously sell ("production decision") and whether to raise or lower its productive capacity ("investment decision"). To be precise, denote the firm's current productive capacity by $K \in \{0, +\infty\}$, with each capacity unit able to produce one output unit per time unit. Since the firm is able to costlessly and instantaneously change its capacity utilization, its current output quantity is $Q \in \{0, K\}$ per time unit.

The firms sells its output at the price $P = \theta - \gamma Q$, where $\theta$ is demand and $\gamma$ the constant elasticity of demand. We assume that $\theta$ obeys geometric Brownian motion (GBM):

$$d\theta = \alpha\theta dt + \sigma\theta dW, \tag{3}$$

where $\alpha$ and $\sigma$ are, respectively, the constant demand drift rate and volatility, and $W$ is a Brownian motion. Given the firm produces output at the variable production cost $c_1 Q + \frac{1}{2} c_2 Q^2$, where $c_1$ and $c_2$ are non-negative parameters, but also incurs a fixed capacity cost of $fK$, where $f$ is another non-negative parameter, its total profits per time unit, $\Pi$, are:

$$\Pi = PQ - c_1 Q - \frac{1}{2} c_2 Q^2 - fK = (\theta - c_1)Q - (\gamma + \frac{1}{2} c_2) Q^2 - fK. \tag{4}$$

Recalling that the firm can costlessly and instantaneously change its capacity utilization, it optimally sets its output quantity $Q$ to $\max\left(\min\left(\frac{\theta - c_1}{2\gamma + c_2}, K\right), 0\right)$ in each instant.

In addition to deciding on its output quantity, the firm can also, in each instant, raise its production capacity $K$ at a unit cost of $k$ or can lower that capacity at a unit sales proceed of $d$, with $k > d$. As first shown by Pindyck (1988), the firm optimally invests into the incremental production unit until the unit's value ("investment benefit") no longer exceeds the investment outlay plus the value of the option to invest into the unit later ("investment cost"). Conversely, the firm disinvests the incremental production unit until the sales proceed plus the value from regaining the option to invest into the unit later ("disinvestment benefit") no longer exceeds the unit's value ("disinvestment cost"). If neither benefit exceeds the corresponding cost, the firm is in an inaction region in which it is optimal to neither invest nor disinvest.

To find the optimal investment and disinvestment policies, we need to make more specific assumptions about the investment process. Consistent with Kydland and Prescott (1982) and Carlson et al. (2010), we thus assume that, when a firm builds new capacity, it takes $\bar{T}$ time units from the investment date for the new capacity to become operational and to generate a non-zero profit ("time-to-build"). In line with Koeva's (2000) survey evidence, we do not allow construction work to be abandoned once it has started. In contrast, when a firm buys new capacity, we conjecture that the capacity is immediately operational (i.e., $\bar{T} = 0$). In agreement with our evidence in Section 3, we next assume that the profits of newly-built capacity are less sensitive to negative demand shocks than the profits of bought capacity. To incorporate that assumption in a parsimonious way, we impose a lower bound on the gross profits that newly-built capacity generates by selling an output increment, denoting that lower bound by $\theta_A > 0$.[17] Since our evidence however also suggests that the lower sensitivity of newly-built capacity disappears over time, we let the lower bound vanish with a fixed probability $\lambda$ per time unit, rendering newly-built capacity equivalent to bought capacity after a while.

Since setting $\bar{T} = 0$ (i.e., no time-to-build) and $\lambda = \infty$ (i.e., no newly-built capacity) renders our model similar to other well-known real options asset pricing models,[18] we effectively argue that those other models consider the case in which firms raise their capacity through asset acquisitions. Allowing for time-to-build as well as for newly-built capacity to differ from bought capacity for some random time period, we extend those other models by also incorporating the case in which firms raise their capacity through physically building new capacity.

## 4.2 Model Solution

In line with Pindyck (1988), Aguerrevere (2009), and Aretz and Pope (2018), we solve the model by separately valuing the firm's options on its incremental output units $s \in \{0, +\infty\}$. To do so, let $V(\theta, s)$ be the current value of a high-profit-sensitivity option to produce output increment $s$ at a demand of $\theta$ (which is either a bought option or a built option after it lost its low profit sensitivity); $V^{nb}(\theta, s)$ the current value of the corresponding newly-built low-profit-sensitivity option; $V^{uc}(\theta, \bar{T}(s), s)$ the current value of the corresponding under-construction option with remaining construction time $\bar{T}(s)$; and $G(\theta, \bar{T}, s)$ the current value of the option to invest into the corresponding under-construction option. As the firm optimally exercises its growth options sequentially (low-$s$-value before high-$s$-value options), we can write firm value $W$ as:

$$W = \int_0^{K^{ap}} V^{ap}(\theta, s)ds + \int_{K^{ap}}^{K} V^{uc}(\theta, \bar{T}(s), s)ds + \int_K^{\infty} G(\theta, \bar{T}, s)ds, \qquad (5)$$

[17] As shown in the appendix, the gross profits generated from output increment $s$ is $\theta - c_1 - (2\gamma + c_2)s$ for bought (mature) capacity. For newly-built capacity, it is therefore $\max(\theta - c_1 - (2\gamma + c_2)s, \theta_A)$.

[18] In fact, further setting $f = 0$, the model collapses to the Aretz and Pope (2018) model.

where $V^{ap}(\theta, s) \in \{V(\theta, s), V^{nb}(\theta, s)\}$ is an option to produce output increment $s$ with a high or low profit sensitivity, and $K^{ap}$ is total installed capacity.[19] Since Equation (5) suggests that the firm can be interpreted as a portfolio of real options, the instantaneous expected firm return, $E[r_A]$, minus the risk-free rate of return, $r$, can be written as:

$$\begin{aligned} E[r_A] - r &= \Bigg( \int_0^{K^{ap}} \frac{V^{ap}(\theta, s)}{W} \Omega_{V^{ap}(\theta,s)} ds \\ &+ \int_{K^{ap}}^{K} \frac{V^{uc}(\theta, \bar{T}(s), s)}{W} \Omega_{V^{uc}(\theta,\bar{T}(s),s)} ds \\ &+ \int_K^{\infty} \frac{G(\theta, \bar{T}, s)}{W} \Omega_{G(\theta,\bar{T},s)} ds \Bigg) \times (\mu - r), \end{aligned} \tag{6}$$

where $\Omega_{V^{ap}(\theta,s)} \in \{\Omega_{V(\theta,s)}, \Omega_{V^{nb}(\theta,s)}\}$, $\Omega_{V(\theta,s)}$, $\Omega_{V^{nb}(\theta,s)}$, $\Omega_{V^{uc}(\theta,\bar{T}(s),s)}$, and $\Omega_{G(\theta,\bar{T},s)}$ are the elasticities of the high and low profit-sensitivity options to produce, the under-construction options to produce, and the growth options, with each elasticity defined as the partial derivative of option value with respect to demand times the ratio of demand to option value. Conversely, $\mu$ is the instantaneous expected return of a demand mimicking portfolio. See, for example, Cox and Rubinstein (1985, p.186) or Appendix B of Carlson et al. (2004).

In Appendix A, we illustrate that the value of the high-profit-sensitivity option to produce output increment $s$ under a current demand of $\theta$, $V(\theta, s)$, is:

$$V(\theta, s) = \begin{cases} F(\theta, s) + d; & \theta \leq \theta^D \\ b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r}; & \theta^D \leq \theta \leq (2\gamma + c_2)s + c_1 \\ b_2\theta^{\beta_2} + \frac{\theta}{\delta} - \frac{(2\gamma+c_2)s+c_1}{r} - \frac{f}{r}; & \theta \geq (2\gamma + c_2)s + c_1, \end{cases} \tag{7}$$

where the $b_1$, $b_2$, $\beta_1$, $\beta_2$, and $\theta^D$ parameters are defined in the appendix, and $\delta \equiv \mu - \alpha$. When $\theta \leq \theta^D$, the firm sells the option, cashing in the sales proceeds and regaining the possibility

[19] Since the firm cannot abandon construction work, $V^{ap}(\theta, s)$ could theoretically also be equal to $G(\theta, \bar{T}, s)$, as in situations in which increases in demand inducing the firm to start new construction work are followed by sharp decreases spurring disinvestment of assets-in-place. Although we could easily accommodate such situations by writing $V^{ap}(\theta, s) \in \{V(\theta, s), V^{nb}(\theta, s), G(\theta, \bar{T}, s)\}$, we ignore them since they do not matter for our calibration exercise studying the effect of real investment on the expected firm return.

to repurchase the option in the future. When $\theta^D \leq \theta \leq (2\gamma + c_2)s + c_1$, the firm retains the option but does not use it to produce output, implying that the option's value stems from the possibilities to use or sell it in the future. Finally, when $\theta \geq (2\gamma + c_2)s + c_1$, the firm uses the option to produce output, implying that the option's value stems from it continuing to produce output forever and the possibility to stop producing output in the future.

In the same appendix, we show that the value of a low-profit-sensitivity option to produce output increment $s$ under a current demand of $\theta$, $V^{nb}(\theta, s)$, is:

$$V^{nb}(\theta, s) = \begin{cases} b_6'\theta^{\beta_1'} + \frac{\theta_A - f}{r+\lambda} + a\theta^{\beta_1} + \frac{\lambda d}{r+\lambda}; & \theta \leq \theta^D \\ b_4'\theta^{\beta_1'} + b_5'\theta^{\beta_2'} + \frac{\theta_A}{r+\lambda} + b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r}; & \theta^D \leq \theta \leq (2\gamma + c_2)s + c_1 \\ b_1'\theta^{\beta_1'} + b_3'\theta^{\beta_2'} + b_2\theta^{\beta_2} - \frac{\theta}{\delta+\lambda} & \\ +\frac{\theta_A + (2\gamma+c_2)s + c_1}{r+\lambda} + \frac{\theta}{\delta} - \frac{(2\gamma+c_2)s+c_1+f}{r}; & 0 \leq \theta - (2\gamma + c_2)s - c_1 \leq \theta^A \\ b_2'\theta^{\beta_2'} + b_2\theta^{\beta_2} + \frac{\theta}{\delta} - \frac{(2\gamma+c_2)s+c_1+f}{r}; & \theta - (2\gamma + c_2)s - c_1 \geq \theta_A, \end{cases} \tag{8}$$

where the new parameters $b_1'$ to $b_6'$, $\beta_1'$, and $\beta_2'$ are defined in the appendix. When $\theta \leq \theta^D$, the firm uses the option to produce a gross profit equal to the lower bound $\theta_A$ but immediately sells it upon the bound disappearing. Conversely, when $\theta^D \leq \theta \leq (2\gamma + c_2)s + c_1$, the firm uses the option to produce the same gross profit but retains it upon the bound disappearing. Next, when $\theta_A \geq \theta - (2\gamma + c_2)s - c_1$, the firm again uses the option to produce the same gross profit but continues to use it to produce a lower albeit still positive gross profit upon the bound disappearing. In all those cases, the value of the option thus derives from the option continuing to produce a gross profit at the lower bound, the possibility that the gross profit rises in the future, and the possibility that the firm either sells, retains, or continues to use the option upon the bound disappearing. Finally, when $\theta - (2\gamma + c_2)s - c_1 \geq \theta_A$, the firm uses the option to produce the same gross profit above the lower bound both in the presence and absence of the bound, implying that the option's value derives from it continuing to generate an above-lower-bound gross profit forever and the possibilities that the gross profit drops either to the lower bound or even below that bound in the future.[20]

Appendix A also shows that the value of an under-construction option to produce output increment $s$ at a demand of $\theta$ and with remaining construction time $\bar{T}(s)$, $V^{uc}(\theta, \bar{T}(s), s)$, is:

$$V^{uc}(\theta, \bar{T}(s), s) = V_1^{uc}(\theta, \bar{T}(s), s) + V_2^{uc}(\theta, \bar{T}(s), s) + V_3^{uc}(\theta, \bar{T}(s), s) + V_4^{uc}(\theta, \bar{T}(s), s), \quad (9)$$

where the $V_1^{uc}(\theta, \bar{T}(s), s)$ to $V_4^{uc}(\theta, \bar{T}(s), s)$ terms are defined in the appendix. As long as an option to produce is under construction, it is uncertain in which of the four regions specified in Equation (8) demand will be at the end of the construction period. As a result, we can interpret the four summands on the right-hand side of Equation (9) as the values of binary options awarding the firm either the corresponding option to produce or nothing at the end of that period. For example, $V_4^{uc}(\theta, \bar{T}(s), s)$ is the value of the binary option possibly awarding the firm the option to produce which is used independent of the lower gross-profit bound.

The appendix finally demonstrates that the value of the growth option to start construction of the option to produce output increment $s$ at a demand of $\theta$ and under a total construction time of $\bar{T}$ and an upfront installation cost of $k$, $G(\theta, \bar{T}, s)$, is:

$$G(\theta, \bar{T}, s) = \begin{cases} e\theta^{\beta_1}; & \theta \leq \theta^* \\ V^{uc}(\theta, \bar{T}, s) - k; & \theta \geq \theta^*, \end{cases} \quad (10)$$

where the $e$ and $\theta^*$ parameters are defined in the appendix. We can interpret $\theta^*$ as the demand threshold at which the firm exercises the option to start construction. Conversely, fixing $\theta$ and finding the amount of installed capacity $K$ for which the value of the marginal production

[20]For simplicity, our solution assumes that it is never optimal to disinvest a low-profit-sensitivity option to produce. Although it is straightforward to accommodate that possibility, doing so complicates the solution without changing the economic intuition behind our model. In fact, in theory, allowing for low-profit-sensitivity options to be disinvested only raises their value whilst lowering their systematic risk, strengthening our later conclusion that only building firms observe a decrease in their expected returns upon investment. In practice, when those firms start building the low-profit-sensitivity options, the options to disinvest them again are so far out-of-the-money that they do not alter the effect of investment on the expected firm return.

unit equals the value of the marginal growth option plus the unit installation cost, we can interpret that amount of capacity as the optimal amount of capacity $K^*$.

## 4.3 Calibration Exercise

We finally show that a calibrated version of the model suggests that only capacity builders but not buyers produce an investment anomaly, with the anomaly, however, disappearing over a small number of years after the investment. To do so, we induce a positive shock to the demand of a firm with an ex-ante optimal capacity $K^*$, leading the firm to either buy or build new capacity. In either case, we assume that the pre- and post-shock demand values are 1.50 and 2.50, respectively. The annualized drift rate, $\alpha$, and volatility, $\sigma$, of demand are, respectively, 0.06 and 0.20. The demand elasticity, $\gamma$, is 0.25. The variable cost parameters, $c_1$ and $c_2$, are, respectively, 0.20 and 0.00, and the fixed cost parameter, $f$, is 0.05. The annualized expected demand-mimicking portfolio return, $\mu$, and risk-free rate of return, $r$, are, respectively, 0.16 and 0.04. For simplicity, we set the proceeds from selling capacity, $d$, to zero.

Consistent with Koeva's (2000) survey evidence, we assume that it takes one-and-a-half years for capacity to be build and become operational (i.e., $\bar{T} = 1.5$). Moreover, the unit gross profits produced by a newly-built capacity increment, $\theta - c_1 - (2\gamma + c_2)s$, are bounded from below by $\theta_A = 0.75$, with the lower bound, however, disappearing with a probability $\lambda$ of 0.10 per annum. We finally set the unit cost of acquiring new capacity, $k$, to one, but the unit cost of building new capacity to 5.05, ensuring that the ex-ante optimal amount of installed capacity, $K^*$, is independent of whether the firm buys or builds the new capacity.[21]

Table 9 shows the effect of demand-induced real investment on a firm's expected excess return in the model separately for the two cases in which the firm buys (Panel A) or builds (Panel B) the new capacity. In addition to the expected excess return, $E[r_A] - r$, the table also reports the installed and optimal amounts of capacity ($K$ and $K^*$, respectively), the fractions

[21] We also assume that all pre-shock installed capacity of a capacity builder is non-newly-built. Assuming that some of that installed capacity is newly-built only serves to strengthen our conclusions.

of firm value attributable to the production $((\int_0^{K^{ap}} V^{ap}(\theta, s)ds + \int_{K^{ap}}^{K} V^{uc}(\theta, \bar{T}(s), s)ds)/W)$ and growth $(\int_K^{\infty} G(\theta, \bar{T}, s)ds/W)$ options, and the (scaled) systematic risk of the production $(\int_0^{K^{ap}} \frac{V^{ap}(\theta,s)}{W}\Omega_{V^{ap}(\theta,s)}ds + \int_{K^{ap}}^{K} \frac{V^{uc}(\theta,\bar{T}(s),s)}{W}\ \Omega_{V^{uc}(\theta,\bar{T}(s),s)}ds)$ and growth $(\int_K^{\infty} \frac{G(\theta,\bar{T},s)}{W}\Omega_{G(\theta,\bar{T},s)}ds)$ options. Notice that the expected excess return is a value-weighted average of the systematic risk of the two option types times the expected excess demand-mimicking-portfolio return $\mu - r$. The rows in each panel report those statistics before the demand shock, after the shock but before investment, and after investment. If the firm builds new capacity, we separately report the after-investment statistics at the start of construction and in the long-run (i.e., after the lower bound on the gross profits of newly-built capacity has disappeared).

Starting with the capacity buyer in Panel A of Table 9, we find that its pre-shock installed and optimal amounts of capacity are both 1.44 (see the first row). Before investment, the shock increases the optimal amount of capacity to 3.10, decreases the systematic risk of both types of options, and skews firm value away from the lower-risk assets-in-place and toward the higher-risk growth options (second row). Since the negative effect on the expected excess return from the lower systematic risk is, however, almost offset by the positive effect from the (relatively) more valuable growth options, the expected excess return of 28% per annum hardly changes. Spurred by the shock, the firm finally buys new capacity, converting higher-risk growth options into lower-risk assets-in-place. Doing so, the firm reverses the two effects on the expected excess return again, without it, however, greatly altering the expected excess return (third row).

Turning to the capacity builder in Panel B, its pre-shock installed and optimal amounts of capacity are also 1.44 under a unit investment cost of 5.05 (see first row). Before investment, the demand shock now increases the optimal amount of capacity to 3.38, while it again exerts a positive effect on the expected excess return through skewing firm value toward the higher-risk growth options and a negative effect through lowering the systematic risk of both types of options (second row). Yet, as before, the two effects almost cancel out each other, leaving the expected excess return virtually unchanged. Spurred by the shock, the firm starts building new capacity, raising its installed capacity (consisting of both assets-in-place and assets-under-construction) to its optimal capacity (third row). While doing so again reverses the positive effect on the expected excess return, just like in case of the capacity buyer, it conversely now however amplifies the negative effect on that return since the assets-under-construction have a lower systematic risk than their corresponding (non-newly-built) assets-in-place. The reason is that the assets-under-construction ultimately transform into newly-built assets with a lower sensitivity to negative demand shocks. The upshot is that the investment induces the expected excess return to drop from 26% per annum to 19%. Yet, as the newly-built capacity ages and loses its lower sensitivity to negative shocks, its systematic risk shoots up, leading the expected excess return to rise back up to close to its pre-investment level (fourth row).

Overall, this section confirms that a real options model of the firm in which building capacity implies that new capacity becomes operational only with some time gap but ultimately yields capacity with a lower sensitivity to demand downturns for some period can reproduce our evidence in Sections 2 and 3. More specifically, such a model can suggest that only the expected returns of capacity builders (but not buyers) decrease with their investments, with the decrease, however, reverting over a small number of years after those investments.

# 5 Concluding Remarks

We present empirical evidence that the tendency of high real-investment stocks to underperform others, the so-called investment anomaly, is almost exclusively attributable to firms physically building new capacity. The evidence emerges in value- and equally-weighted double portfolio sorts, FM regressions featuring interaction terms between investment and construction, and subsample FM regressions separately run on constructing and non-constructing firms. Moreover, it is robust to alternative methodological choices and holds for alternative investment proxies used in the literature. While cross-sectional and time-series variations in investment intensity, financing sources, profitability, and asset or market size are unable to explain why constructing firms drive the investment anomaly, the data suggest that the gross profits of constructing firms become less sensitive to industry downturns a number of years after construction, perhaps due to newly-built assets being more operationally flexible than mature assets. We finally tie together our empirical evidence in a real options model of the firm in which building capacity implies that new capacity becomes operational only with some time gap but ultimately yields capacity which is less sensitive to negative demand shocks for some period. Calibrating the model, we show that our evidence is consistent with neoclassical finance theory.

# References

Agrawal, Anup, and Jeffrey F. Jaffe, 2000, The post-merger performance puzzle, in: Cooper, G., Gregory, A. (Eds.), *Advances in Mergers and Acquisitions* 1, Elsevier, Amsterdam, 7-41.

Aguerrevere, Felipe L., 2009, Real options, product market competition, and asset returns, *Journal of Finance* 64, 957-983.

Anderson, Chistopher W., and Luis Garcia-Feijóo, 2006, Empirical evidence on capital investment, growth options, and security returns, *Journal of Finance* 61, 171-194.

Aretz, Kevin, and Peter F. Pope, 2018, Real options models of the firm, capacity overhang, and the cross section of stock returns, *Journal of Finance* 73, 1363-1415.

Bali, Turan, Stephen Brown, and Yi Tang, 2017, Is economic uncertainty priced in the cross-section of stock returns?, *Journal of Financial Economics* 126, 471–489.

Carlson, Murray, Adlai Fisher, and Ron Giammarino, 2004, Corporate investment and asset price dynamics, *Journal of Finance* 59, 2577-2603.

Carlson, Murray, Adlai Fisher, and Ron Giammarino, 2006, Corporate investment and asset price dynamics: Implications for SEO event studies and long-run performance, *Journal of Finance* 61, 1009-1034.

Carlson, Murray, Adlai Fisher, and Ron Giammarino, 2010, SEO risk dynamics, *Review of Financial Studies* 23, 4026-4077.

Chang, Yongsung and Sunoong Hwang, 2015, Asymmetric phase shifts in US industrial production cycles, *Review of Economics and Statistics* 97, 116-133.

Cooper, Ilan, 2006, Asset pricing implications of non-convex adjustment costs and irreversibility of investment, *Journal of Finance* 61, 139-170.

Cooper, Ilan, and Richard Priestley, 2011, Real investment and risk dynamics, *Journal of Financial Economics* 101, 182-205.

Cooper, Michael J., Huseyin Gulen, and Michael J. Schill, 2008, Asset growth and the cross-section of stock returns, *Journal of Finance* 63, 1609-1651.

Cooper, Russell W., and John C. Haltiwanger, 2006, On the nature of capital adjustment costs, *Review of Economic Studies* 73, 611-633.

Cox, John C., and Mark Rubinstein, 1985, *Options Markets* (Prentice Hall, Englewood Cliffs, NJ).

Doms, Mark, and Timothy Dunne, 1998, Capital adjustment patterns in manufacturing plants, *Review of Economic Dynamics* 1, 409-429.

Doshi, Hiteshi, Kris Jacobs, Praveen Kumar, and Ramon Rabinovitch, 2019, Leverage and the cross-section of equity returns, *Journal of Finance* 74, 1431-1471.

Fama, Eugene F., and Kenneth R. French, 2006, Profitability, investment, and average returns, *Journal of Financial Economics* 82, 491-518.

Fama, Eugene F., and Kenneth R. French, 2008, Dissecting anomalies, *Journal of Finance* 63, 1653-1678.

Fama, Eugene F., and Kenneth R. French, 2015, A five-factor asset pricing model, *Journal of Financial Economics* 116, 1-22.

Fama, Eugene F., and Kenneth R. French, 2016, Dissecting anomalies with a five-factor model, *Review of Financial Studies* 29, 69-103.

Fama, Eugene F., and James D. MacBeth, 1973, Risk, return, and equilibrium: Empirical tests, *Journal of Political Economy* 71, 607-636.

Fine, Charles H., and Robert M. Freund, 1990, Optimal investment in product-flexible manufacturing capacity, *Management Science* 36, 449-466.

Hackbarth, Dirk, and Timothy C. Johnson, 2015, Real options and risk dynamics, *Review of Economic Studies* 82, 1449-1482.

He, Hua, and Robert S. Pindyck, 1992, Investments in flexible production capacity, *Journal of Economic Dynamics and Control* 16, 575-599.

Hou, Kewei, Chen Xue, and Lu Zhang, 2015, Digesting anomalies: An investment approach, *Review of Financial Studies* 28, 650-705.

Jensen, Michael, 1986, The agency costs of free cash flow: Corporate finance and takeovers, *American Economic Review* 76, 323-329.

Koeva, Petya, 2000, The facts about time-to-build, IMF Working Paper Series.

Koste, Lori L., and Manoj K. Malhotra, 1999, A theoretical framework for analyzing the dimensions of manufacturing flexibility, *Journal of Operations Management* 18, 75-93.

Kydland, Finn E., and Edward C. Prescott, 1982, Time to build and aggregate fluctuations, *Econometrica* 50, 1345-1370.

Lamont, Owen A., 2000, Investment plans and stock returns, *Journal of Finance* 55, 2719-2745.

Majd, Saman, and Robert S.Pindyck, 1987, Time to build, option value, and investment decisions, *Journal of Financial Economics* 18, 7-27.

Milgrom, Paul and John Roberts, 1990, The economics of modern manufacturing: Technology, strategy, and organization, *American Economic Review* 80, 511-528.

Myers, Stewart C., 1977, Determinants of corporate borrowing, *Journal of Financial Economics* 5, 147-175.

Newey, Whitney K., and Kenneth D. West, 1987, A simple positive-definite heteroskedasticity and autocorrelation consistent covariance matrix, *Econometrica* 55, 703-708.

Novy-Marx, Robert, 2013, The other side of value: The gross profitability premium, *Journal of Financial Economics* 108, 1-28.

Peters, Ryan H., and Lucian A.Taylor, 2017, Intangible capital and the investment-q relation, *Journal of Financial Economics* 123, 251-272.

Pindyck, Robert S., 1988, Irreversible investment, capacity choice, and the value of the firm, *American Economic Review* 78, 969-985.

Pindyck, Robert S., 1993, Investments of uncertain cost, *Journal of Financial Economics* 34, 53-76.

Rau, Raghavendra, and Theo Vermaelen, 1998, Glamour, value and the post-acquisition performance of acquiring firms, *Journal of Financial Economics* 49, 223-253.

Sagi, Jacob S., and Mark S. Seasholes, 2007, Firm-specific attributes and the cross-section of momentum, *Journal of Financial Economics* 84, 389-434.

Shumway, Tyler, 1997, The delisting bias in CRSP data, *Journal of Finance* 52, 327-340.

Titman, Sheridan, K. C. John Wei, and Feixue Xie, 2004, Capital investments and stock returns, *Journal of Financial and Quantitative Analysis* 39, 677-700.

Tolio, Tullio, 2009, Design of Flexible Production Systems: Methodologies and Tools. *Springer*.

Triantis, Alexander J., and James E. Hodder, 1990, Valuing flexibility as a complex option, *Journal of Finance* 45, 549-565.

Upton, David M., 1995, What really makes factories flexible? *Harvard Business Review* 73, 74-84.

White, Halbert, 1980, A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity, *Econometrica* 48, 817-838.

Xing, Yuhang, 2008, Interpreting the value effect through the Q-theory: An empirical investigation, *Review of Financial Studies* 21, 1767-1795.

**Table 1**
**Descriptive Statistics**

The table presents descriptive statistics for *Investment*, *Construction*, and *ConstructionIndictor* (Panel A) and all Pearson cross-correlations within the set of those variables and our control variables (Panel B). The descriptive statistics include the mean, the standard deviation, skewness, kurtosis, and several percentiles. We calculate the descriptive statistics and correlations by month and then average over our sample period. With the exception of skewness and kurtosis, the statistics for *Investment*, *Construction*, and *ConstructionIndicator* are reported in percentage terms. See Table AI in Appendix A for more details about the variable definitions.

| | *Investment* | *Construction* | *Construction Indicator* |
|---|---|---|---|
| | (1) | (2) | (3) |
| Panel A: Descriptive Statistics | | | |
| Mean | 9.15 | 1.13 | 0.37 |
| Standard Deviation | 13.69 | 2.70 | 0.48 |
| Skewness | 4.07 | 4.16 | 0.54 |
| Kurtosis | 24.63 | 24.78 | 1.40 |
| Percentile 1 | 0.13 | 0.00 | 0.00 |
| Percentile 5 | 0.56 | 0.00 | 0.00 |
| First Quartile | 2.35 | 0.00 | 0.00 |
| Median | 4.99 | 0.00 | 0.01 |
| Third Quartile | 10.14 | 0.97 | 1.00 |
| Percentile 95 | 31.47 | 5.73 | 1.00 |
| Percentile 99 | 78.01 | 14.40 | 1.00 |
| Panel B: Average Pearson Correlations | | | |
| *Construction* | 0.19 | | |
| *ConstructionIndicator* | 0.00 | 0.55 | |
| *MarketBeta* | 0.08 | 0.04 | −0.01 |
| *MarketSize* | 0.01 | 0.11 | 0.11 |
| *BookToMarket* | −0.05 | −0.06 | −0.02 |
| *Momentum* | −0.07 | −0.02 | 0.01 |
| *Profitability* | 0.03 | 0.04 | 0.06 |

**Table 2**
**Univariate Investment Portfolios**

The table presents the mean returns and alphas of portfolios univariately sorted on *Investment*. At the end of June of each calendar year $t$, we sort stocks into four portfolios according to the tenth, 50th, and 90th percentiles of the *Investment* distribution in that month. We value- (Panel A) or equally-weight (Panel B) the portfolios and hold them from start-July of year $t$ to end-June of year $t+1$. We also form a spread portfolio long the highest and short the lowest investment portfolio ("LS90-10"). Columns (1) to (3) report the mean number of stocks and the time-series means of the value- (Panel A) or equally-weighted (Panel B) cross-sectional means of *Investment* and *Construction* per portfolio, respectively. The plain numbers in columns (4) to (6) are, respectively, the mean excess returns and alphas of the $q$-theory and five-factor (FF5) model (excluding their investment factors), annualized and in percent. The numbers in square brackets in the same columns are $t$-statistics obtained from Newey and West's (1987) formula with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Mean Number Stocks | Mean *Investment* | Mean *Construction* | Mean Excess Return | $q$-Theory Model Alpha | FF5 Model Alpha |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Panel A: Value-Weighted Portfolios | | | | | | |
| 00-10 | 158 | 0.54 | 0.72 | 9.67 | 1.58 | 0.18 |
| 10-50 | 632 | 2.92 | 1.22 | 8.31 | 0.59 | 0.41 |
| 50-90 | 632 | 9.24 | 2.01 | 7.97 | 0.84 | 1.19 |
| 90-100 | 158 | 43.61 | 2.72 | 3.82 | −3.62 | −5.13 |
| LS90–10 | | | | −5.84 | −5.20 | −5.30 |
| $t$-statistic | | | | [−2.18] | [−2.15] | [−2.09] |
| Panel B: Equally-Weighted Portfolios | | | | | | |
| 00-10 | 158 | 0.54 | 0.46 | 11.37 | 4.62 | 1.44 |
| 10-50 | 632 | 2.85 | 0.84 | 10.96 | 3.80 | 1.26 |
| 50-90 | 632 | 9.64 | 2.07 | 9.78 | 2.41 | −0.01 |
| 90-100 | 158 | 46.19 | 5.41 | 3.94 | −2.96 | −6.67 |
| LS90–10 | | | | −7.43 | −7.58 | −8.11 |
| $t$-statistic | | | | [−2.99] | [−3.36] | [−3.52] |

**Table 3**
**Double-Sorted Portfolios on Investment and Construction**

The table presents the mean returns and alphas of portfolios double-sorted on *Investment* and *ConstructionIndicator*. At the end of June of each calendar year $t$, we sort stocks into four portfolios according to the tenth, 50th, and 90th percentiles of the *Investment* distribution in that month. We independently sort them into two portfolios according to whether *ConstructionIndicator* is zero or one in that month. The intersection of the two sets gives us the double-sorted portfolios. We value- (Panel A) and equally-weight (Panel B) the portfolios and hold them from start-July of year $t$ to end-June of year $t+1$. Within each *Construction* portfolio, we also form a spread portfolio long the highest and short the lowest investment portfolio ("LS90-10"). Columns (1) to (3) report the mean number of stocks and the time-series means of the value- (Panel A) or equally-weighted (Panel B) cross-sectional means of *Investment* and *Construction* per portfolio. The plain numbers in columns (4) to (6) are, respectively, the mean excess returns and alphas of the $q$-theory and five-factor (FF5) model (excluding their investment factors), annualized and in percent. The numbers in square brackets in the same columns are Newey and West's (1987) $t$-statistics with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Mean Number Stocks | Mean *Investment* | Mean *Construction* | Mean Excess Return | $q$-Theory Model Alpha | FF5 Model Alpha |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Panel A: Value-Weighted Portfolios | | | | | | |
| Panel A.1: Constructing Stocks | | | | | | |
| 00-10 | 41 | 0.54 | 2.04 | 12.03 | 3.56 | 2.12 |
| 10-50 | 225 | 3.02 | 2.82 | 8.04 | 0.03 | −0.39 |
| 50-90 | 267 | 9.19 | 4.73 | 8.97 | 1.61 | 2.18 |
| 90-100 | 56 | 36.68 | 8.88 | −0.32 | −6.84 | −5.69 |
| LS90–10 (1) | | | | −12.35 | −10.40 | −7.81 |
| $t$-statistic | | | | [−3.21] | [−2.94] | [−2.48] |
| Panel A.2: Non-Constructing Stocks | | | | | | |
| 00-10 | 117 | 0.55 | 0.00 | 9.58 | 1.61 | 0.15 |
| 10-50 | 408 | 2.84 | 0.00 | 8.80 | 1.15 | 1.06 |
| 50-90 | 365 | 9.30 | 0.00 | 7.22 | 0.21 | 0.37 |
| 90-100 | 102 | 45.17 | 0.00 | 5.63 | −1.60 | −4.45 |
| LS90–10 (2) | | | | −3.95 | −3.21 | −4.60 |
| $t$-statistic | | | | [−1.31] | [−1.13] | [−1.52] |

*(continued on next page)*

**Table 3**
**Double-Sorted Portfolios on Investment and Construction (cont.)**

| | Mean Number Stocks | Mean *Investment* | Mean *Construction* | Mean Excess Return | $q$-Theory Model Alpha | FF5 Model Alpha |
|---|---|---|---|---|---|---|
| Panel B: Equally-Weighted Portfolios | | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Panel B.1: Constructing Stocks | | | | | | |
| 00-10 | 41 | 0.56 | 1.34 | 14.27 | 7.04 | 3.63 |
| 10-50 | 225 | 2.96 | 1.95 | 11.26 | 4.00 | 1.20 |
| 50-90 | 267 | 9.74 | 3.94 | 10.18 | 2.81 | −0.07 |
| 90-100 | 56 | 38.19 | 9.32 | 2.28 | −5.14 | −7.56 |
| LS90–10 (1) | | | | −11.99 | −12.18 | −11.19 |
| $t$-statistic | | | | [−5.28] | [−5.48] | [−5.81] |
| Panel B.2: Non-Constructing Stocks | | | | | | |
| 00-10 | 117 | 0.54 | 0.00 | 10.47 | 3.91 | 0.82 |
| 10-50 | 408 | 2.79 | 0.00 | 10.62 | 3.50 | 1.05 |
| 50-90 | 365 | 9.60 | 0.00 | 9.52 | 2.20 | 0.08 |
| 90-100 | 102 | 50.28 | 0.00 | 5.09 | −1.41 | −5.89 |
| LS90–10 (2) | | | | −5.39 | −5.32 | −6.71 |
| $t$-statistic | | | | [−1.70] | [−1.80] | [−2.20] |

**Table 4**
**Regressions of Stock Returns on Investment Interacted with Construction**
The table presents the results from Fama-MacBeth (1973) regressions of stock returns over month $t$ on various combinations of investment, construction, and control variables measured until the end of month $t-1$. In columns (1) to (3), we report the results from full-sample regressions on either *Investment* and the controls; *Investment*, an interaction between *Investment* and *Construction*, *Construction*, and the controls; and *Investment*, an interaction between *Investment* and a rank variable based on *Construction*, the rank variable, and the controls, respectively. In columns (4) and (5), we report the results from subsample regressions run separately on firms with a positive or zero *Construction* value, respectively. Column (4)–(5) finally reports the difference in estimates across the subsample regressions. The plain numbers are monthly premium estimates, stated in percent. The numbers in square brackets are Newey and West (1987) $t$-statistics with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Full-Sample Regressions | | | Subsample Regressions | | |
|---|---|---|---|---|---|---|
| | Only Main Effects | Main Effects & Interaction | Main Effects & Rank Interaction | Cons. Stocks | Non-Cons. Stocks | Diff. |
| | (1) | (2) | (3) | (4) | (5) | (4)–(5) |
| *Investment* | −1.01 | −0.72 | −0.69 | −2.14 | −0.54 | −1.60 |
| | [−3.17] | [−2.16] | [−1.91] | [−6.58] | [−1.57] | [−3.94] |
| *Investment* × *Construction* | | −29.46 | | | | |
| | | [−3.27] | | | | |
| *Construction* | | 2.23 | | | | |
| | | [1.52] | | | | |
| *Investment* × *ConstructionRank* | | | −2.17 | | | |
| | | | [−3.14] | | | |
| *ConstructionRank* | | | 0.18 | | | |
| | | | [1.94] | | | |
| *MarketBeta* | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 |
| | [−0.01] | [0.00] | [0.01] | [0.05] | [0.02] | [0.08] |
| *MarketSize* | −0.03 | −0.04 | −0.04 | −0.07 | −0.02 | −0.05 |
| | [−0.69] | [−0.77] | [−0.80] | [−1.48] | [−0.47] | [−1.84] |

*(continued on next page)*

**Table 4**
**Regressions of Stock Returns on Investment Interacted with Construction (cont.)**

| | Full-Sample Regressions | | | Subsample Regressions | | |
|---|---|---|---|---|---|---|
| | Only Main Effects | Main Effects & Interaction | Main Effects & Rank Interaction | Cons. Stocks | Non-Cons. Stocks | Diff. |
| | (1) | (2) | (3) | (4) | (5) | (4)–(5) |
| *BookToMarket* | 0.21 | 0.21 | 0.21 | 0.08 | 0.26 | −0.19 |
| | [2.57] | [2.49] | [2.49] | [0.71] | [3.26] | [−2.17] |
| *Momentum* | 0.89 | 0.89 | 0.89 | 0.79 | 0.96 | −0.17 |
| | [4.16] | [4.14] | [4.16] | [3.28] | [4.54] | [−1.21] |
| *Profitability* | 0.55 | 0.54 | 0.55 | 0.47 | 0.54 | −0.07 |
| | [3.24] | [3.21] | [3.23] | [2.27] | [2.93] | [−0.38] |
| Constant | 0.92 | 0.93 | 0.92 | 1.15 | 0.86 | 0.29 |
| | [2.09] | [2.12] | [2.10] | [2.69] | [1.91] | [1.57] |

**Table 5**
**Repeating the Regressions Using Alternative Screens and Proxies**
The table presents the investment premium estimates from full-sample (row (1)) and subsample (rows (2) and (3)) Fama-MacBeth (1973) regressions of stock returns over month $t$ on investment and control variables measured until the end of month $t-1$ using alternative sample screens and proxy variables. The subsample regressions in rows (2) and (3) are separately run on firms with a positive or zero *Construction* value, respectively. Row (2)–(3) reports the difference in the investment premium estimates across the subsamples. In column (1), we exclude observations with missing *Construction* values from our sample. In column (2), we identify constructing firms as those firms with a positive PPE-CIP balance at the start and/or end of the fiscal year ending in calendar year $t-1$. In column (3), we retain service firms. In column (4), we retain firms with sales below $25 million over the fiscal year ending in calendar year $t-1$ over the period from start-July of calendar year $t$ to end-June of calendar year $t+1$. In column (5), we remove stocks with a price below $5 (but not those with a market capitalization below the first quartile) at the end of June of calendar year $t$ over the period from start-July of calendar year $t$ to end-June of calendar year $t+1$. In column (6), we use delevered stock returns as dependent variable in the regression. The control variables are the same as those used in the regressions in Table 4. The plain numbers are the monthly investment premium estimates or their differences across the subsamples, stated in percent. The numbers in square brackets are Newey and West (1987) $t$-statistics with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Exclude Missing Cons. Obs. | Use 2-Year Cons. Average | Retain Service Stocks | Retain Sales < $25m Stocks | Use Price Filter | Un-lever Stock Returns |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Full Sample (1) | −1.61 | −1.01 | −1.12 | −1.11 | −0.75 | −0.59 |
| | [−5.44] | [−3.17] | [−3.82] | [−3.56] | [−2.44] | [−3.09] |
| Constructing Stocks (2) | −2.14 | −2.10 | −1.84 | −2.23 | −1.72 | −1.33 |
| | [−6.58] | [−6.40] | [−6.18] | [−7.29] | [−5.09] | [−6.04] |
| Non-Constructing Stocks (3) | −0.53 | −0.57 | −0.77 | −0.65 | −0.38 | −0.29 |
| | [−1.07] | [−1.60] | [−2.24] | [−1.92] | [−1.12] | [−1.44] |
| Difference (2)–(3) | −1.61 | −1.52 | −1.06 | −1.58 | −1.34 | −1.04 |
| | [−2.92] | [−3.69] | [−2.54] | [−3.90] | [−3.09] | [−4.07] |

**Table 6**
**Repeating the Regressions Using Alternative Investment Proxies**
The table presents the investment premium estimates from full-sample (row (1)) and subsample (rows (2) and (3)) Fama-MacBeth (1973) regressions of stock returns over month $t$ on investment and control variables measured until the end of month $t-1$ using alternative investment proxy variables. The subsample regressions in rows (2) and (3) are separately run on firms with a positive or zero *Construction* value, respectively. Row (2)–(3) reports the difference in the investment premium estimates across the subsamples. In column (1), we use our main investment proxy, *Investment*. In column (2), we use the ratio of CAPEX to gross property, plant, and equipment. In column (3), we use the ratio of CAPEX to sales over its moving average taken over the prior three years. In column (4), we use the percentage growth in total (i.e., physical plus intangible) productive capacity. In column (5), we use the percentage growth in total assets. The control variables are the same as those used in the regressions in Table 4. The plain numbers are the monthly investment premium estimates or their differences across the subsamples, stated in percent. The numbers in square brackets are Newey and West (1987) $t$-statistics with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Our Investment Proxy | CAPEX-to-PPE | Abnormal CAPEX | Capital Growth | Assets Growth |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Full Sample (1) | −1.12 | −0.80 | −0.14 | −0.49 | −0.38 |
| | [−3.82] | [−4.71] | [−3.79] | [−5.59] | [−5.57] |
| Constructing Stocks (2) | −1.84 | −1.20 | −0.20 | −0.73 | −0.59 |
| | [−6.18] | [−4.50] | [−3.26] | [−5.28] | [−4.93] |
| Non-Constructing Stocks (3) | −0.77 | −0.59 | −0.09 | −0.41 | −0.37 |
| | [−2.24] | [−3.46] | [−1.92] | [−4.00] | [−5.08] |
| Difference (2)–(3) | −1.06 | −0.62 | −0.11 | −0.32 | −0.21 |
| | [−2.54] | [−2.43] | [−1.48] | [−2.05] | [−1.70] |

**Table 7**

**A Comparison of Firm Fundamentals Across Constructing and Other Stocks**

The table compares a number of firm characteristics across high-investment constructing and non-constructing stocks over the investment year and the five following years. We identify high-investment stocks as those with an *Investment* value above the last decile at the end of each fiscal year $t$ in our sample period. We next split those stocks into constructing and non-constructing stocks according to whether they have a positive or zero *Construction* value at the same time, respectively. Excluding stocks for which we are unable to calculate a firm fundamental for fiscal years $t$ to $t+5$, we then calculate the mean firm fundamental value by constructing (row (1))/non-constructing (row (2)) stock and fiscal year (columns (1) to (6)). We finally average over our sample period. Row (1)–(2) reports the difference in the mean firm fundamental value across constructing and non-construction stocks by fiscal year, while column (7) reports the change in the mean value over the six fiscal years by subsample. The plain numbers are mean estimates or their differences across the two types of stocks. The numbers in square brackets are Newey and West (1987) $t$-statistics with a six-month lag length. See Table AI in Appendix A for more details about variable definitions.

| | Year Relative to Investment Year | | | | | | Difference | |
|---|---|---|---|---|---|---|---|---|
| | 0 | +1 | +2 | +3 | +4 | +5 | +5–0 | $t$-stat. |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| | | | | Panel A: Investment | | | | |
| Cons. Stocks (1) | 0.20 | 0.11 | 0.09 | 0.09 | 0.08 | 0.07 | −0.13 | [−8.24] |
| Non-Cons. Stocks (2) | 0.23 | 0.15 | 0.13 | 0.12 | 0.12 | 0.10 | −0.14 | [−8.43] |
| Difference (1)–(2) | −0.04 | −0.03 | −0.04 | −0.03 | −0.04 | −0.03 | | |
| $t$-statistic (3) | [−3.57] | [−3.09] | [−3.01] | [−2.29] | [−3.45] | [−4.24] | | |
| | | | | Panel B: Equity Financing | | | | |
| Cons. Stocks (1) | 0.10 | 0.05 | 0.03 | 0.03 | 0.02 | 0.02 | −0.09 | [−3.43] |
| Non-Cons. Stocks (2) | 0.11 | 0.06 | 0.04 | 0.04 | 0.04 | 0.03 | −0.08 | [−4.26] |
| Difference (1)–(2) | 0.00 | −0.01 | −0.01 | −0.01 | −0.02 | −0.01 | | |
| $t$-statistic (3) | [−0.02] | [−1.20] | [−1.83] | [−2.82] | [−4.70] | [−3.99] | | |
| | | | | Panel C: Debt Financing | | | | |
| Cons. Stocks (1) | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | −0.01 | [−3.39] |
| Non-Cons. Stocks (2) | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | −0.01 | [−3.34] |
| Difference (1)–(2) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| $t$-statistic (3) | [−0.11] | [−1.11] | [−0.16] | [0.16] | [−0.15] | [0.35] | | |

*(continued on next page)*

**Table 7**
**A Comparison of Firm Fundamentals Across Constructing and Other Stocks (cont.)**

| | Year Relative to Investment Year | | | | | | Difference | |
|---|---|---|---|---|---|---|---|---|
| | 0 | +1 | +2 | +3 | +4 | +5 | +5–0 | *t*-stat. |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| **Panel D: Profitability** | | | | | | | | |
| Cons. Stocks (1) | 0.30 | 0.30 | 0.28 | 0.27 | 0.28 | 0.29 | 0.00 | [−0.08] |
| Non-Cons. Stocks (2) | 0.29 | 0.28 | 0.27 | 0.28 | 0.27 | 0.28 | −0.01 | [−0.67] |
| Difference (1)–(2) | 0.00 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | | |
| *t*-statistic (3) | [0.40] | [1.57] | [0.70] | [−0.69] | [0.56] | [0.67] | | |
| **Panel E: Market Size (in billion $)** | | | | | | | | |
| Cons. Stocks (1) | 3.57 | 3.75 | 4.12 | 4.53 | 4.84 | 5.28 | 1.71 | [2.34] |
| Non-Cons. Stocks (2) | 5.08 | 5.59 | 5.74 | 6.30 | 6.64 | 6.91 | 1.83 | [4.28] |
| Difference (1)–(2) | −1.51 | −1.84 | −1.62 | −1.78 | −1.80 | −1.63 | | |
| *t*-statistic (3) | [−1.48] | [−1.68] | [−1.48] | [−1.57] | [−1.51] | [−1.38] | | |
| **Panel F: Total Assets (in billion $)** | | | | | | | | |
| Cons. Stocks (1) | 2.50 | 2.72 | 2.96 | 3.22 | 3.43 | 3.61 | 1.11 | [13.92] |
| Non-Cons. Stocks (2) | 4.06 | 4.65 | 5.11 | 5.50 | 5.95 | 6.35 | 2.30 | [5.00] |
| Difference (1)–(2) | −1.56 | −1.93 | −2.15 | −2.28 | −2.52 | −2.74 | | |
| *t*-statistic (3) | [−1.92] | [−2.08] | [−2.13] | [−2.12] | [−2.19] | [−2.30] | | |
| **Panel G: Book-to-Market** | | | | | | | | |
| Cons. Stocks (1) | 0.57 | 0.62 | 0.65 | 0.66 | 0.67 | 0.67 | 0.10 | [1.65] |
| Non-Cons. Stocks (2) | 0.59 | 0.64 | 0.66 | 0.67 | 0.69 | 0.69 | 0.10 | [2.07] |
| Difference (1)–(2) | −0.02 | −0.02 | −0.01 | −0.01 | −0.03 | −0.03 | | |
| *t*-statistic (3) | [−0.60] | [−0.71] | [−0.35] | [−0.47] | [−0.90] | [−0.67] | | |

**Table 8**

**Profit Regressions on Industry Conditions Interacted with Construction**

The table presents the results from panel regressions of a firm's profit growth over calendar quarter $t$ on its industry's average-output-good price growth over that period, average-output-good price growth interacted with a dummy variable equal to one if the firm engages in construction work over the period from year $q$ to $w$ and else zero, controls, and firm and time fixed effects. While columns (1) and (2) show the results from full-sample regressions, columns (3) to (6) show those from subsample regressions including only observations with a past two-year average-output-good price growth above ((3) and (5)) and below ((4) and (6)) the full-sample median. In column (1), we set $Construction^{(q,w)}$ equal to one if a firm has a positive PPE-CIP balance in at least one of the five years directly following the current quarter $t$ and else zero ("pre-construction"). In contrast, in columns (2) to (4) ((5) and (6)), we set that variable equal to one if the firm has a positive balance in at least one of the five years directly before (five years before) the current quarter $t$ and else zero ("post-construction"). Plain numbers are coefficient estimates, while the numbers in square brackets are $t$-statistics calculated using White (1980) standard errors. See Tables AI, AII, and AIII in Appendix A for variable and industry definitions, respectively.

| | | | Regression: | | | |
|---|---|---|---|---|---|---|
| | | | (2) | (2) | (3) | (4) |
| | Before Building Work | After Building Work | High Past *Industry Price Growth* Subsample | Low Past *Industry Price Growth* Subsample | Later After Building Work | Later After Building Work |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *IndustryPriceGrowth* | 0.41 | 0.41 | 0.39 | 0.48 | 0.31 | 0.42 |
| | [7.66] | [8.37] | [4.84] | [6.99] | [3.50] | [5.72] |
| *IndustryPriceGrowth* | 0.06 | −0.23 | −0.12 | −0.35 | −0.10 | −0.19 |
| × $Construction^{(q,w)}$ | [0.33] | [−3.45] | [−1.13] | [−3.86] | [−0.82] | [−1.85] |
| *LagProfitGrowth* | −20.07 | −19.81 | −19.85 | −21.23 | −17.36 | −20.72 |
| | [−23.29] | [−32.81] | [−22.26] | [−24.00] | [−15.58] | [−17.91] |
| *QuarterlyReturn* | 1.11 | 0.93 | 1.02 | 0.83 | 0.93 | 0.76 |
| | [15.55] | [20.41] | [15.52] | [12.23] | [11.95] | [9.11] |
| *Momentum* | 0.24 | 0.20 | 0.19 | 0.21 | 0.20 | 0.18 |
| | [7.95] | [9.27] | [6.14] | [6.55] | [5.25] | [4.54] |
| *MarketSize* | −0.21 | −0.17 | −0.23 | −0.15 | −0.18 | −0.11 |
| | [−7.09] | [−9.20] | [−7.74] | [−5.20] | [−5.21] | [−3.30] |

*(continued on next page)*

**Table 8**
**Profit Regressions on Industry Conditions Interacted with Construction (cont.)**

| | | | Regression: | | | |
|---|---|---|---|---|---|---|
| | | | (2) | (2) | (3) | (4) |
| | Before Building Work | After Building Work | High Past *Industry Price Growth* Subsample | Low Past *Industry Price Growth* Subsample | Later After Building Work | Later After Building Work |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *BookToMarket* | −0.38 | −0.32 | −0.36 | −0.28 | −0.27 | −0.26 |
| | [−9.77] | [−13.30] | [−9.23] | [−8.29] | [−6.33] | [−6.75] |
| $Construction^{(q,w)}$ | 0.11 | −0.04 | −0.08 | −0.01 | 0.05 | 0.02 |
| | [1.27] | [−0.86] | [−1.26] | [−0.10] | [0.65] | [0.23] |
| *Constant* | 1.21 | 1.08 | 1.40 | 0.91 | 1.13 | 0.69 |
| | [7.43] | [9.68] | [8.19] | [5.34] | [5.20] | [3.20] |
| Firm/Time F.E.s | Yes | Yes | Yes | Yes | Yes | Yes |
| Adjusted $R^2$ | 0.06 | 0.05 | 0.05 | 0.06 | 0.04 | 0.05 |

**Table 9**
**Expected Returns and Investment**
The table presents the effect of real investment on the expected firm return implied from a real options model of the firm in which the firm buys (Panel A) or builds (Panel B) new capacity. While column (1) shows current demand, columns (2) to (4) report, respectively, the firm's installed capacity, capacity-under-construction, and optimal capacity implied by current demand. In turn, columns (5) and (7) give the fractions of firm value attributable to the assets-in-place (installed assets plus assets-under-construction) and growth options of the firm, while columns (6) and (8) show the systematic risk of those two type of assets, all respectively. In column (9), we finally report the expected firm return. The basecase parameters are as follows. The drift rate, $\alpha$, and volatility, $\sigma$, of demand are 0.06 and 0.20 per annum, respectively. The elasticity of demand, $\gamma$, is 0.25. The cost parameters, $c_1$ and $c_2$, are 0.20 and zero, respectively. The unit investment cost, $k$, is one in the buying case in Panel A and 5.05 in the building case in Panel B. The expected return of the demand mimicking portfolio, $\mu$, is 0.16 per annum. The risk-free rate of return, $r_f$, is 0.04 per annum. The operating cost, $f$, is 0.05, while the proceeds from disinvestment, $d$, are zero. In the building case in Panel B, we assume a time-to-build, $\bar{T}$, of 1.5, a lower bound on the gross profits produced by newly-built capacity increments, $\theta_A$, of 0.75, and a probability that the lower bound disappears, $\lambda$, of 0.10 per annum. The statistics in the penultimate row in Panel B are measured at the start of the construction period, while those in the final row are measured after all newly-built capacity increments have lost their lower gross-profit bounds.

| | Inst. Cap. | Under Cons. Cap. | Opt. Cap. | Assets-in-Place + Assets Under Cons. | | Growth Options | | Exp. |
|---|---|---|---|---|---|---|---|---|
| Demand $\theta$ | $K^{ap}$ | $K^{uc}$ | $K^*$ | Weight | Risk | Weight | Risk | Return |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Panel A: Buying New Capacity | | | | | | | | |
| 1.50 | 1.44 | 0.00 | 1.44 | 0.82 | 1.92 | 0.18 | 4.45 | 0.28 |
| 2.50 | 1.44 | 0.00 | 3.10 | 0.59 | 1.52 | 0.41 | 3.40 | 0.27 |
| 2.50 | 3.10 | 0.00 | 3.10 | 0.87 | 1.86 | 0.13 | 4.45 | 0.26 |
| Panel B: Building New Capacity | | | | | | | | |
| 1.50 | 1.44 | 0.00 | 1.44 | 0.90 | 1.92 | 0.11 | 4.45 | 0.26 |
| 2.50 | 1.44 | 0.00 | 3.38 | 0.71 | 1.52 | 0.29 | 3.65 | 0.26 |
| 2.50 (start cons.) | 1.44 | 1.94 | 3.38 | 0.93 | 1.41 | 0.07 | 4.45 | 0.19 |
| 2.50 (long-term) | 3.38 | 0.00 | 3.38 | 0.93 | 1.91 | 0.07 | 4.45 | 0.25 |

# Appendix A. Variable and Industry Definitions

**Table AI**
**Analysis Variables Used In Our Asset Pricing and Comparison Tests**
The table gives the definitions of the variables used in our asset pricing and comparison tests. We show the variable mnemonics of the data providers (CRSP and Compustat) in parentheses. We use the calculated values from July of year $t$ to June of year $t+1$. The exceptions are *MarketBeta*, *MarketSize*, and *Momentum*, whose calculated values are used only in month $t$.

| Variable Name | Variable Definition |
|---|---|
| | Panel A: Investment Proxies |
| *Investment* | The change in gross property, plant, and equipment (ppegt) over the fiscal year ending in calendar year $t-1$ scaled by total assets (at) at the start of that fiscal year. |
| *CAPEX-to-PPE* | The ratio of capital expenditures (capx) from the fiscal year ending in calendar year $t-1$ to gross property, plant and equipment (ppegt) from that fiscal year (see Xing (2008)). |
| *AbnormalCAPEX* | The ratio of capital expenditures (capx) scaled by sales (sale) from the fiscal year ending in calendar year $t-1$ to the average of that ratio taken over the fiscal years ending in calendar years $t-2$, $t-3$, and $t-4$ minus one (see Titman et al. (2004)). |
| *CapitalGrowth* | The percentage growth in total capital over the fiscal year ending in calendar year $t-1$, where total capital is the sum of physical capital and intangible capital. Physical capital is gross property, plant and equipment (ppegt), whereas intangible capital is the estimated replacement cost of intangible capital (see Peters and Taylor (2017)). |
| *AssetsGrowth* | The percentage growth in total assets (at) over the fiscal year ending in calendar year $t-1$ (see Cooper et al. (2008)). |
| | Panel B: Construction Variables |
| *Construction* | The ratio of gross property, plant, and equipment under construction (fatc) from the fiscal year ending in calendar year $t-1$ to total assets (at) from the fiscal year ending in calendar year $t-2$. |

*(continued on next page)*

**Table AI**
**Analysis Variables Used In Our Asset Pricing and Comparison Tests (cont.)**

| Variable Name | Variable Definition |
|---|---|
| | Panel B: Construction Variables (cont.) |
| *ConstructionIndicator* | A binary variable equal to one if *Construction* is positive and else zero. |
| *ConstructionRank* | A variable taking the value of zero if *Construction* is zero and else the rank of *Construction*. |
| | Panel C: Control and Other Variables |
| *MarketBeta* | The slope coefficient from a stock-level regression of excess return (ret) on excess market return, where the regression is run using daily data over the prior twelve months. We require that the regression is run on at least non-missing 200 observations. |
| *MarketSize* | Log of the product of the stock price (abs(prc)) times common shares outstanding divided by 1,000 (shrout). |
| *BookToMarket* | Log of the ratio of book value-to-market value of equity (abs(prc) $\times$ shrout), where the book value of equity is equal to total assets (at) minus total liabilities (lt) plus deferred taxes (txditc, zero if missing) minus preferred stock (pstkl, pstkrv, prfstck, or zero, in that order of availability). While the market value of equity is from the end of December of calendar year $t-1$, the variables underlying the book value of equity are from the fiscal year end in calendar year $t-1$. |
| *Momentum* | Log of the compounded stock return (ret) over the period from month $t-12$ to month $t-2$. We require the stock return to be non-missing for at least nine months over that period. |
| *Profitability* | Ratio of sales (sale) net of costs of goods sold (cogs), selling, general, and administrative expenses (xsga), and interest expenses (xint) to the book value of equity, where the book value of equity is total assets (at) minus total liabilities (lt) plus deferred taxes (txditc, zero if missing) minus preferred stock (pstkl, pstkrv, or zero, in that order of availability). All variables are from the fiscal year end in calendar year $t-1$. |
| *EquityFinancing* | The change in equity financing over the fiscal year ending in calendar year $t-1$ scaled by total assets (at) at the start of that fiscal year. Equity financing is preferred stock (pstk) plus common equity (ceq) plus minority interest (mib) minus retained earnings (re). |
| *DebtFinancing* | The change in debt financing over the fiscal year ending in calendar year $t-1$ scaled by total assets (at) at the start of that fiscal year. Debt financing is total current liabilities (dlc). |
| *TotalAssets* | Total assets (at) from the fiscal year end in calendar year $t-1$. |

**Table AII**
**Additional Analysis Variables Used In Our Panel Profit-Growth Regressions**
The table presents the definitions of the variables used in the panel profit-growth regressions in Table 8. We give the variable mnemonics of the data providers (CRSP and Compustat) in parentheses. We calculate the control variables *Momentum*, *MarketSize*, and *BookToMarket* used in those regressions as detailed in Table AI, not repeating their definitions here.

| Variable Name | Variable Definition |
|---|---|
| *ProfitGrowth* | The change in gross profits (saleq minus cogsq) over calendar quarter $t$ scaled by total assets (atq) at the start of that quarter. |
| *IndustryPriceGrowth* | The ratio of the gross-sales growth of an industry over calendar quarter $t$ to the gross production growth of that industry over the same quarter minus one. In case of firm $i$ belonging to industry $k$, we estimate industry $k$'s total sales by aggregating the sales (saleq) of all firms belonging to that industry except for firm $i$. We estimate an industry's production growth using its industrial production index obtained from the Federal Reserve's G.17 database. |
| $Construction^{q,w}$ | A binary variable equal to one if a firm has a positive *Construction* value in at least one year over the period from year $q$ to $w$ and else zero, where $q$ and $w$ are relative to the current year (so, e.g., $q = 1$ and $w = 5$ indicate the five-year period following the current year). |
| *LagProfitGrowth* | The one-quarter lagged value of *ProfitGrowth*. |
| *QuarterlyReturn* | The compounded stock return (ret) over calendar quarter $t$. |

**Table AIII**
**Industry Classifications**
The table presents the 32 NAICS industries used to construct *IndustryPriceGrowth* in Table 8.

| NAICS | Industry Name |
|---|---|
| 315 | Apparel |
| 316 | Leather and allied product |
| 323 | Printing and related support activities |
| 324 | Petroleum and coal products |
| 3114 | Fruit and vegetable preserving and specialty food |
| 3116 | Animal slaughtering and processing |
| 3119 | Other food |
| 3121 | Beverage |
| 3221 | Pulp, paper, and paperboard mills |
| 3222 | Converted paper product |
| 3251 | Basic chemical |
| 3252 | Resin, synthetic rubber, and artificial and synthetic fibers and filaments |
| 3253 | Pesticide, fertilizer, and other agricultural chemical |
| 3254 | Pharmaceutical and medicine |
| 3256 | Soap, cleaning compound, and toilet preparation |
| 3261 | Plastics product |
| 3311,2 | Iron and steel products |
| 3314 | Nonferrous metal (except aluminum) production and processing |
| 3329 | Other fabricated metal product |
| 3331 | Agriculture, construction, and mining machinery |
| 3332 | Industrial machinery |
| 3333,9 | Commercial and service industry machinery and other general purpose machinery |
| 3334 | Ventilation, heating, air-conditioning, and commercial refrigeration equipment |
| 3343 | Audio and video equipment |
| 3345 | Navigational, measuring, electromedical, and control instruments |
| 3353 | Electrical equipment |

*(continued on next page)*

**Table AIII**
**Industry Classifications (cont.)**

| NAICS | Industry Name |
|---|---|
| 3359 | Other electrical equipment and component |
| 3361 | Motor vehicle |
| 3363 | Motor vehicle parts |
| 3364 | Aerospace product and parts |
| 3371 | Household and institutional furniture and kitchen cabinet |
| 3391 | Medical equipment and supplies |

# Appendix B. Real Options Model Solution

In this appendix, we derive the solution of the real options model in Section 4. To do so, we separately value the *incremental* mature, newly-built, and under-construction production option and the growth option allowing the firm to build the production option, all on output increment $s$. Assuming markets are complete and complete spanning holds, we obtain their values through contingent claims analysis. We finally also determine that productive capacity $K^*$ maximizing firm value net of capacity installation costs ("optimal capacity").

## B.1 Valuing Mature Production Options

We first value the incremental mature production option on output increment $s$. That option yields a payoff of $\theta - (2\gamma + c_2)s - c_1 - f$ when switched on to produce output and a payoff of $-f$ when switched off. Moreover, it can be disinvested at a sales proceed of $d$. To do the valuation, we form a portfolio long the option and short $m$ units of an asset whose value perfectly replicates the value of demand. Denoting the value of the option to produce by $V(\theta, s)$, the value of the portfolio is $V(\theta, s) - m\theta$, and the change in its value is:

$$dV(\theta, s) + \pi(\theta, s)dt - md\theta - m\delta\theta dt, \tag{B1}$$

where $\pi(\theta, s)$ is the payoff of the incremental production option. Using Itô's lemma and plugging in for $\theta$, we can rewrite the change in portfolio value as:

$$\begin{aligned} & V_\theta(\theta, s)d\theta + \frac{1}{2}V_{\theta\theta}(\theta, s)d\theta d\theta + \pi(\theta, s)dt - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt & \text{(B2)} \\ = \;& \alpha\theta V_\theta(\theta, s)dt + \sigma\theta V_\theta(\theta, s)dW + \frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}(\theta, s)dt & \\ + \;& \pi(\theta, s)dt - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt. & \text{(B3)} \end{aligned}$$

Setting $m$ equal to $V_\theta(\theta, s)$, the change in portfolio value becomes deterministic and must be equal to the payoff from an equally-sized risk-free investment:

$$\frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}(\theta, s)dt + \pi(\theta, s)dt - \delta\theta V_\theta(\theta, s)dt = r(V(\theta, s) - V_\theta(\theta, s)\theta)dt. \tag{B4}$$

Rearranging and dividing by $dt$, we obtain the ordinary differential equation:

$$\frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}(\theta, s) + (r - \delta)\theta V_\theta(\theta, s) - rV(\theta, s) + \pi(\theta, s) = 0, \tag{B5}$$

which the value of the incremental option has to satisfy subject to boundary conditions.

When $\theta - (2\gamma + c_2)s - c_1 - f > -f$ or, alternatively, $\theta$ exceeds the production threshold $\theta^P \equiv (2\gamma + c_2)s + c_1$, it is optimal for the firm to switch on the option to produce output. Under these circumstances, the value of the option is given by:

$$V(\theta, s) = b_2\theta^{\beta_2} + \frac{\theta}{\delta} - \frac{(2\gamma + c_2)s + c_1}{r} - \frac{f}{r}, \tag{B6}$$

where $b_2$ is a free parameter and:

$$\beta_2 = -(r - \delta - \sigma^2/2)/\sigma^2 - \sqrt{(r - \delta - \sigma^2/2)^2 + 2r\sigma^2}/\sigma^2. \tag{B7}$$

Conversely, when $\theta$ falls below the production threshold $\theta^P$, it is optimal for the firm to switch off the option, and the value of the option is given by:

$$V(\theta, s) = b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r}, \tag{B8}$$

where $b_1$ and $b_3$ are free parameters and:

$$\beta_1 = -(r - \delta - \sigma^2/2)/\sigma^2 + \sqrt{(r - \delta - \sigma^2/2)^2 + 2r\sigma^2}/\sigma^2. \tag{B9}$$

Finally, when $\theta$ falls below the disinvestment threshold $\theta^D$, it is optimal for the firm to sell off the option, and the value of the option is given by:

$$V(\theta, s) = F(\theta, s) + d, \tag{B10}$$

where $F(\theta, s)$ is the value of the option to repurchase the mature production option.

To identify the values of $b_1$ to $b_3$ and $\theta^D$, we start by ensuring that Equation (B6) value-matches with and smooth-pastes into Equation (B8) at the production threshold $\theta^P$:

$$b_2(\theta^P)^{\beta_2} + \frac{(\theta^P)}{\delta} - \frac{(2\gamma + c_2)s + c_1}{r} = b_1(\theta^P)^{\beta_1} + b_3(\theta^P)^{\beta_2}, \tag{B11}$$

$$b_2\beta_2(\theta^P)^{\beta_2 - 1} + \frac{1}{\delta} = b_1\beta_1(\theta^P)^{\beta_1 - 1} + b_3\beta_2(\theta^P)^{\beta_2 - 1}. \tag{B12}$$

Solving Equations (B11) and (B12) for $b_1$ and $(b_2 - b_3)$, we obtain:

$$b_1 = \frac{r - \beta_2(r - \delta)}{r\delta(\beta_1 - \beta_2)}[(2\gamma + c_2)s + c_1]^{1-\beta_1}, \tag{B13}$$

$$(b_2 - b_3) = \frac{r - \beta_1(r - \delta)}{r\delta(\beta_1 - \beta_2)}[(2\gamma + c_2)s + c_1]^{1-\beta_2}. \tag{B14}$$

To identify the remaining parameter values, we need to value the option to repurchase the mature option to produce. Using the same argumentation as above, the value of that option, $F(\theta, s)$, must fulfill the ordinary differential equation:

$$\frac{1}{2}\sigma^2\theta^2 F_{\theta\theta}(\theta, s) + (r - \delta)\theta F_\theta(\theta, s) - rF(\theta, s) = 0. \tag{B15}$$

Denote the demand level at or above which the firm exercises the option to repurchase the mature production option (i.e., the investment threshold) by $\theta^\perp$. When demand is below that threshold, the value of the option to repurchase the production option is equal to:

$$F(\theta, s) = a\theta^{\beta_1}, \tag{B16}$$

where $a$ is a free parameter. In the opposite case, it is equal to:

$$F(\theta, s) = V(\theta, s) - k, \tag{B17}$$

where $k$ is the unit repurchase cost of the mature production option.

Plugging Equation (B16) into Equation (B10) and letting Equation (B8) value-match with and smooth-paste into Equation (B10) at the disinvestment threshold $\theta^D$, we obtain:

$$b_1(\theta^D)^{\beta_1} + b_3(\theta^D)^{\beta_2} - \frac{f}{r} = a(\theta^D)^{\beta_1} + d, \tag{B18}$$

$$b_1\beta_1(\theta^D)^{\beta_1-1} + b_3\beta_2(\theta^D)^{\beta_2-1} = a\beta_1(\theta^D)^{\beta_1-1}. \tag{B19}$$

Conditional on the value of $a$, we solve Equations (B18) and (B19) for $b_3$ and $\theta^D$, yielding:

$$\theta^D = \left[\frac{\beta_2(f/r+d)}{(a-b_1)(\beta_1-\beta_2)}\right]^{\frac{1}{\beta_1}}, \tag{B20}$$

$$b_3 = \frac{\beta_1(f/r+d)}{\beta_1-\beta_2}\left[\frac{\beta_2(f/r+d)}{(a-b_1)(\beta_1-\beta_2)}\right]^{-\frac{\beta_2}{\beta_1}} \tag{B21}$$

which, in combination with Equation (B14), also yields $b_2$.

To identify $a$ and $\theta^\perp$, we ensure that Equation (B16) value-matches with and smooth-pastes into Equation (B17) at the investment threshold, yielding:

$$b_2(\theta^\perp)^{\beta_2} + \frac{(\theta^\perp)}{\delta} - \frac{(2\gamma+c_2)s+c_1}{r} - \frac{f}{r} - k = a(\theta^\perp)^{\beta_1}, \tag{B22}$$

$$b_2\beta_2(\theta^\perp)^{\beta_2-1} + \frac{1}{\delta} = a\beta_1(\theta^\perp)^{\beta_1-1}. \tag{B23}$$

Conditional on the value of the investment threshold $\theta^{\perp}$, we find that:

$$a = b_2 \frac{\beta_2}{\beta_1} (\theta^{\perp})^{\beta_2 - \beta_1} + \frac{1}{\delta \beta_1} (\theta^{\perp})^{1-\beta_1}. \tag{B24}$$

Plugging Equation (B24) into Equation (B22), Equation (B22) becomes an implicit function of the investment threshold $\theta^{\perp}$ alone, which can be numerically solved for $\theta^{\perp}$.

## B.2 Valuing Newly-Built Productions Options

We next value the newly-built production option on output increment $s$. The gross profit of that newly-built production option, $\theta - (2\gamma + c_2)s - c_1$, is bounded from below by $\theta_A$, with the lower bound, however, disappearing with a fixed probability of $\lambda$ per time unit. As before, we also use contingent claims analysis to value that option. To do so, we again form a portfolio long the incremental option and short $m$ units of an asset whose value perfectly replicates the value of demand. Denoting the value of the newly-built option to produce by $V^{nb}(\theta, s)$, we can write the value of the portfolio as $V^{nb}(\theta, s) - m\theta$ and the change in portfolio value as:

$$dV^{nb}(\theta, s) + \pi(\theta, s)dt - md\theta - m\delta\theta dt, \tag{B25}$$

Using Itô's lemma and plugging in for $\theta$, we can rewrite the change in portfolio value as:

$$\begin{aligned}
& V^{nb}_{\theta}(\theta, s)d\theta + \frac{1}{2} V^{nb}_{\theta\theta}(\theta, s)d\theta d\theta + \pi(\theta, s)dt \\
+ \;& \mathbb{I}(\lambda)(V(\theta, s) - V^{nb}(\theta, s)) - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt && \text{(B26)} \\
= \;& \alpha\theta V^{nb}_{\theta}(\theta, s)dt + \sigma\theta V^{nb}_{\theta}(\theta, s)dW + \frac{1}{2}\sigma^2\theta^2 V^{nb}_{\theta\theta}(\theta, s)dt + \pi(\theta, s)dt \\
+ \;& \mathbb{I}(\lambda)(V(\theta, s) - V^{nb}(\theta, s)) - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt, && \text{(B27)}
\end{aligned}$$

where $\mathbb{I}(\lambda)$ is an indicator variable equal to one when the newly-build production option becomes mature and else zero. Setting $m$ equal to $V_\theta^{nb}(\theta, s)$, we are left with:

$$\frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}^{nb}(\theta, s)dt - \delta\theta V_\theta^{nb}(\theta, s)dt + \pi(\theta, s)dt + \mathbb{I}(\lambda)(V(\theta, s) - V^{nb}(\theta, s)). \tag{B28}$$

While Equation (B28) is not deterministic, its expectation is equal to the payoff from an equally-sized risk-free investment if the probability of the newly-built production option becoming a mature production option is idiosyncratic. In that case, we can write:

$$\begin{aligned} & \frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}^{nb}(\theta, s)dt - \delta\theta V_\theta^{nb}(\theta, s)dt + \pi(\theta, s)dt + \lambda(V(\theta, s) - V^{nb}(\theta, s))dt \\ = \; & r(V^{nb}(\theta, s) - V_\theta^{nb}(\theta, s)\theta)dt. \end{aligned} \tag{B29}$$

Rearranging and dividing by $dt$, we obtain the ordinary differential equation that a newly-built production option needs to satisfy subject to boundary conditions:

$$\frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}^{nb}(\theta, s) + (r - \delta)\theta V_\theta^{nb}(\theta, s) - (r + \lambda)V^{nb}(\theta, s) + \pi(\theta, s) + \lambda V(\theta, s) = 0. \tag{B30}$$

When $\theta - (2\gamma + c_2)s - c_1 - f > \theta_A - f$ or $\theta \geq \theta^\diamond \equiv (2\gamma + c_2)s + c_1 + \theta_A$, the firm uses the newly-built production option to produce a gross profit above the lower bound and continues to use the option to produce the same gross profit in case the lower bound is lost. In that case, the value of the newly-built production option is given by:

$$V^{nb}(\theta, s) = b_2'\theta^{\beta_2'} + b_2\theta^{\beta_2} + \frac{\theta}{\delta} - \frac{[(2\gamma + c_2)s + c_1] + f}{r}, \tag{B31}$$

where $b_2'$ is a free parameter and:

$$\beta_2' = -(r - \delta - \sigma^2/2)/\sigma^2 - \sqrt{(r - \delta - \sigma^2/2)^2 + 2(r + \lambda)\sigma^2}/\sigma^2. \tag{B32}$$

When $\theta_A - f > \theta - (2\gamma + c_2)s - c_1 - f > -f$ or, alternatively, $\theta^{\diamond} > \theta > (2\gamma + c_2)s + c_1$, the firm uses the newly-built production option to produce a gross profit at the lower bound and continues to use the option to produce a lower gross profit once the lower bound is lost. In that case, the value of the newly-built production option is equal to:

$$V^{nb}(\theta, s) = b_1'\theta^{\beta_1'} + b_3'\theta^{\beta_2'} + b_2\theta^{\beta_2} - \frac{\theta}{\delta + \lambda} + \frac{\theta_A + (2\gamma + c_2)s + c_1}{r + \lambda} + \frac{\theta}{\delta} - \frac{(2\gamma + c_2)s + c_1 + f}{r}, \tag{B33}$$

where $b_1'$ and $b_3'$ are free parameters and:

$$\beta_1' = -(r - \delta - \sigma^2/2)/\sigma^2 + \sqrt{(r - \delta - \sigma^2/2)^2 + 2(r + \lambda)\sigma^2}/\sigma^2. \tag{B34}$$

When $\theta_A - f > -f > \theta - (2\gamma + c_2)s - c_1 - f > \theta^D$ or $\theta^D < \theta < (2\gamma + c_2)s + c_1$, the firm uses the newly-built production option to produce a gross profit at the lower bound, but switches off the option and thus produces a zero gross profit once the lower bound is lost. In that case, the value of the newly-built production option is equal to:

$$V^{nb}(\theta, s) = b_4'\theta^{\beta_1'} + b_5'\theta^{\beta_2'} + \frac{\theta_A}{r + \lambda} + b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r}, \tag{B35}$$

where $b_4'$ and $b_5'$ are free parameters. Finally, when $\theta < \theta^D$, the firm uses the newly-built production option to produce a gross profit at the lower bound, but disinvests the option once the lower bound is lost. In that case, the value of the newly-built option is equal to:

$$V^{nb}(\theta, s) = b_6'\theta^{\beta_1'} + \frac{\theta_A - f}{r + \lambda} + a\theta^{\beta_1} + \frac{\lambda d}{r + \lambda}, \tag{B36}$$

where $b_6$ is a free parameter. Excluding a $\theta^{\beta_2'}$ term, Equation (B36) implicitly assumes that the value of the lower bound is so high that it is never optimal for the firm to disinvest a newly-built production option (which would, e.g., be the case if disinvesting a newly-built option implied that the firm only regained the option to purchase the equivalent mature option and $\theta_A - f + \lambda d - (r+\lambda)\bar{d} > 0$, with $\bar{d}$ the disinvestment price of the newly-built option).

To determine the values of $b_1'$ and $(b_2' - b_3')$, we ensure that Equation (B31) value-matches with and smooth-pastes into Equation (B33) at the lower-bound threshold $\theta^{\diamond}$:

$$b_2'(\theta^{\diamond})^{\beta_2'} = b_1'(\theta^{\diamond})^{\beta_1'} + b_3'(\theta^{\diamond})^{\beta_2'} - \frac{(\theta^{\diamond})}{\delta+\lambda} + \frac{\theta_A + (2\gamma + c)s + c_1}{r+\lambda}, \quad \text{(B37)}$$

$$b_2'\beta_2'(\theta^{\diamond})^{\beta_2'-1} = b_1'\beta_1'(\theta^{\diamond})^{\beta_1'-1} + b_3'\beta_2'(\theta^{\diamond})^{\beta_2'-1} - \frac{1}{\delta+\lambda}. \quad \text{(B38)}$$

Solving Equations (B37) and (B38) for $b_1'$ and $(b_2' - b_3')$, we obtain:

$$b_1' = \frac{(r+\lambda) - \beta_2'(r-\delta)}{(r+\lambda)(\delta+\lambda)(\beta_1' - \beta_2')}(\theta^{\diamond})^{1-\beta_1'}, \quad \text{(B39)}$$

$$(b_2' - b_3') = \frac{(r+\lambda) - \beta_1'(r-\delta)}{(r+\lambda)(\delta+\lambda)(\beta_1' - \beta_2')}(\theta^{\diamond})^{1-\beta_2'}. \quad \text{(B40)}$$

To determine the values of $(b_1' - b_4')$ and $(b_3' - b_5')$, we ensure that Equation (B33) value-matches with and smooth-pastes into Equation (B35) at the production threshold $\theta^P$:

$$\begin{aligned} & b_1'(\theta^P)^{\beta_1'} + b_3'(\theta^P)^{\beta_2'} + b_2(\theta^P)^{\beta_2} - \frac{(\theta^P)}{\delta+\lambda} + \frac{(2\gamma+c)s + c_1}{r+\lambda} \\ + \; & \frac{(\theta^P)}{\delta} - \frac{(2\gamma + c_2)s + c_1}{r} = b_4'(\theta^P)^{\beta_1'} + b_5'(\theta^P)^{\beta_2'} + b_1(\theta^P)^{\beta_1} + b_3(\theta^P)^{\beta_2}, \quad \text{(B41)} \\ & b_1'\beta_1'(\theta^P)^{\beta_1'-1} + b_3'\beta_2'(\theta^P)^{\beta_2'-1} + b_2\beta_2(\theta^P)^{\beta_2-1} - \frac{1}{\delta+\lambda} + \frac{1}{\delta} \\ = \; & b_4'\beta_1'(\theta^P)^{\beta_1'-1} + b_5'\beta_2'(\theta^P)^{\beta_2'-1} + b_1\beta_1(\theta^P)^{\beta_1-1} + b_3\beta_2(\theta^P)^{\beta_2-1}. \quad \text{(B42)} \end{aligned}$$

Solving Equations (B41) and (B42) for $(b'_1 - b'_4)$ and $(b'_3 - b'_5)$, we obtain:

$$
\begin{aligned}
(b'_1 - b'_4) &= \frac{b_1(\beta'_2 - \beta_1)}{\beta'_2 - \beta'_1}(\theta^P)^{\beta_1 - \beta'_1} + \frac{(b_2 - b_3)(\beta_2 - \beta'_2)}{\beta'_2 - \beta'_1}(\theta^P)^{\beta_2 - \beta'_1} \\
&+ \lambda \frac{r(r+\lambda) - \beta'_2(r(r+\lambda) - \delta(\delta+\lambda))}{r\delta(\delta+\lambda)(r+\lambda)(\beta'_2 - \beta'_1)}(\theta^P)^{1-\beta'_1}, \qquad \text{(B43)} \\
(b'_3 - b'_5) &= \frac{b_1(\beta_1 - \beta'_1)}{\beta'_2 - \beta'_1}(\theta^P)^{\beta_1 - \beta'_2} + \frac{(b_2 - b_3)(\beta'_1 - \beta_2)}{\beta'_2 - \beta'_1}(\theta^P)^{\beta_2 - \beta'_2} \\
&- \lambda \frac{r(r+\lambda) - \beta'_1(r(r+\lambda) - \delta(\delta+\lambda))}{r\delta(\delta+\lambda)(r+\lambda)(\beta'_2 - \beta'_1)}(\theta^P)^{1-\beta'_2}. \qquad \text{(B44)}
\end{aligned}
$$

To determine the values of $(b'_4 - b'_6)$ and $b'_5$, we finally ensure that Equation (B35) value-matches with and smooth-pastes into Equation (B36) at the disinvestment threshold $\theta^D$:

$$
\begin{aligned}
b'_4\theta^{\beta'_1} + b'_5\theta^{\beta'_2} + b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r} &= b'_6\theta^{\beta'_1} - \frac{f}{r+\lambda} + a\theta^{\beta_1} + \frac{\lambda d}{r+\lambda}, \qquad \text{(B45)} \\
b'_4\beta'_1\theta^{\beta'_1 - 1} + b'_5\beta'_2\theta^{\beta'_2 - 1} + b_1\beta_1\theta^{\beta_1 - 1} + b_3\beta_2\theta^{\beta_2 - 1} &= b'_6\beta'_1\theta^{\beta'_1 - 1} + a\beta_1\theta^{\beta_1 - 1}. \qquad \text{(B46)}
\end{aligned}
$$

Solving Equations (B45) and (B46) for $(b'_4 - b'_6)$ and $b'_5$, we obtain:

$$
\begin{aligned}
(b'_4 - b'_6) &= (a - b_1)\frac{(\beta_1 - \beta'_2)}{(\beta'_1 - \beta'_2)}(\theta^D)^{\beta_1 - \beta'_1} - b_3\frac{(\beta_2 - \beta'_2)}{(\beta'_1 - \beta'_2)}(\theta^D)^{\beta_2 - \beta'_1} \\
&- \frac{\beta'_2}{(\beta'_1 - \beta'_2)}\left(\frac{\lambda f}{r(r+\lambda)} + \frac{\lambda d}{(r+\lambda)}\right)(\theta^D)^{-\beta'_1}, \qquad \text{(B47)} \\
b'_5 &= (a - b_1)\frac{(\beta'_1 - \beta_1)}{(\beta'_1 - \beta'_2)}(\theta^D)^{\beta_1 - \beta'_2} - b_3\frac{(\beta'_1 - \beta_2)}{(\beta'_1 - \beta'_2)}(\theta^D)^{\beta_2 - \beta'_2} \\
&+ \frac{\beta'_1}{(\beta'_1 - \beta'_2)}\left(\frac{\lambda f}{r(r+\lambda)} + \frac{\lambda d}{(r+\lambda)}\right)(\theta^D)^{-\beta'_2}. \qquad \text{(B48)}
\end{aligned}
$$

Using Equation (B39) in combination with (B43), we are able to recover $b'_4$, which we use in Equation (B47) to recover $b'_6$. Using Equation (B48) in combination with (B44), we are able to recover $b'_3$, which we use in Equation (B40) to recover $b'_2$.

## B.3 Valuing Production Options-Under-Construction

We next value the production option-under-construction on output increment $s$. That option cannot produce output and thus yields a zero (gross and total) profit over a construction period with initial length of $\bar{T}$ and remaining length (after construction has started) of $\bar{T}(s)$. After construction, the production option-under-construction converts into a newly-built production option. Again using contingent claims analysis, we form a portfolio long the production option-under-construction and short $m$ units of an asset whose value perfectly replicates the value of demand. Denoting the value of that option by $V^{uc}(\theta, \bar{T}(s), s)$, we can write the value of the portfolio as $V^{uc}(\theta, \bar{T}(s), s) - m\theta$ and the change in portfolio value as:

$$dV^{uc}(\theta, \bar{T}(s), s) - md\theta - m\delta\theta dt. \tag{B49}$$

Using Itô's Lemma and plugging in for $\theta$, we obtain:

$$\begin{aligned}
& V^{uc}_{\theta}(\theta, \bar{T}(s), s)d\theta + \frac{1}{2}V^{uc}_{\theta\theta}(\theta, \bar{T}(s), s)d\theta d\theta \\
+ \quad & V^{uc}_{\bar{T}}(\theta, \bar{T}(s), s)d\bar{T} - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt & \text{(B50)} \\
= \quad & \alpha\theta V^{uc}_{\theta}(\theta, \bar{T}(s), s)dt + \sigma\theta V^{uc}_{\theta}(\theta, \bar{T}(s), s)dW + \frac{1}{2}\sigma^2\theta^2 V^{uc}_{\theta\theta}(\theta, \bar{T}(s), s)dt \\
+ \quad & V^{uc}_{\bar{T}}(\theta, \bar{T}(s), s)d\bar{T} - \alpha m\theta dt - \sigma m\theta dW - m\delta\theta dt, & \text{(B51)}
\end{aligned}$$

Noting that $d\bar{T} = -dt$ and setting $m = V^{uc}_{\theta}(\theta, \bar{T}(s), s)$, the portfolio payoff becomes deterministic and thus needs to be equal to the payoff from an equally-sized risk-free investment:

$$\begin{aligned}
& \frac{1}{2}\sigma^2\theta^2 V^{uc}_{\theta\theta}(\theta, \bar{T}(s), s)dt - V^{uc}_{\bar{T}}(\theta, \bar{T}(s), s)dt - \delta\theta V^{uc}_{\theta}(\theta, \bar{T}(s), s)dt \\
= \quad & r(V^{uc}(\theta, \bar{T}(s), s) - \theta V^{uc}_{\theta}(\theta, \bar{T}(s), s))dt, & \text{(B52)}
\end{aligned}$$

Dividing by $dt$ and rearranging, we obtain the partial differential equation:

$$\frac{1}{2}\sigma^2\theta^2 V_{\theta\theta}^{uc}(\theta,\bar{T}(s),s)+(r-\delta)\theta V_{\theta}^{uc}(\theta,\bar{T}(s),s)-rV^{uc}(\theta,\bar{T}(s),s)-V_{\bar{T}}^{uc}(\theta,\bar{T}(s),s)=0, \quad \text{(B53)}$$

which $V^{uc}(\theta,\bar{T}(s),s)$ must obey subject to boundary conditions.

Let $s$, $n$, and $p$ be arbitrary constants. We then note that both:

$$V^{uc}(\theta,\bar{T}(s),s)=s\theta^n e^{-\delta_1(n)\bar{T}(s)}N\left[\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}(s)}}{p}\right)+(r+\frac{1}{2}\sigma^2)\bar{T}(s)}{\sigma\sqrt{\bar{T}(s)}}\right] \quad \text{(B54)}$$

and

$$V^{uc}(\theta,\bar{T}(s),s)=s\theta^n e^{-\delta_1(n)\bar{T}(s)}N\left[-\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}(s)}}{p}\right)+(r+\frac{1}{2}\sigma^2)\bar{T}(s)}{\sigma\sqrt{\bar{T}(s)}}\right], \quad \text{(B55)}$$

where:

$$\delta_1(n)=r-(r-\delta)n-\frac{1}{2}\sigma^2 n(n-1) \quad \text{(B56)}$$

and

$$\delta_2(n)=\delta-\sigma^2(n-1), \quad \text{(B57)}$$

satisfy the partial differential equation. As a next step, we choose $s$, $n$, and $p$ to fulfill the boundary conditions. As demand $\theta$ goes to infinity, $V^{uc}(\theta,\bar{T}(s),s)$ must converge to $\frac{\theta}{\delta}-\frac{[(2\gamma+c_2)s+c_1]+f}{r}$ discounted over the construction time $\bar{T}(s)$. As demand $\theta$ goes to zero, $V^{uc}(\theta,\bar{T}(s),s)$ must converge to $\frac{\theta_A-f}{r+\lambda}+\frac{\lambda d}{r+\lambda}$ discounted over the construction time $\bar{T}(s)$. As the construction time

$\bar{T}(s)$ converges to zero, the following four equation must hold:

$$\lim_{\bar{T}(s)\to 0} V^{uc}(\theta,\bar{T}(s),s) = b_2'\theta^{\beta_2'} + b_2\theta^{\beta_2} + \frac{\theta}{\delta} - \frac{(2\gamma+c_2)s+c_1+f}{r} \quad \text{for } \theta > \theta^{\diamond}, \tag{B58}$$

$$\lim_{\bar{T}(s)\to 0} V^{uc}(\theta,\bar{T}(s),s) = b_1'\theta^{\beta_1'} + b_3'\theta^{\beta_2'} + b_2\theta^{\beta_2} - \frac{\theta}{\delta+\lambda} + \frac{\theta_A + (2\gamma+c_2)s+c_1}{r+\lambda} + \frac{\theta}{\delta} - \frac{(2\gamma+c_2)s+c_1+f}{r} \quad \text{for } \theta^{\diamond} \geq \theta > \theta^{P}, \tag{B59}$$

$$\lim_{\bar{T}(s)\to 0} V^{uc}(\theta,\bar{T}(s),s) = b_4'\theta^{\beta_1'} + b_5'\theta^{\beta_2'} + \frac{\theta_A}{r+\lambda} + b_1\theta^{\beta_1} + b_3\theta^{\beta_2} - \frac{f}{r} \quad \text{for } \theta^{P} \geq \theta > \theta^{D}, \tag{B60}$$

$$\lim_{\bar{T}(s)\to 0} V^{uc}(\theta,\bar{T}(s),s) = b_6'\theta^{\beta_1'} + \frac{\theta_A - f}{r+\lambda} + a\theta^{\beta_1} + \frac{\lambda d}{r+\lambda} \quad \text{for } \theta^{D} \geq \theta. \tag{B61}$$

For arbitrary constants $p_1$ and $p_2$, we now define:

$$\Theta(\theta,n,p_1,p_2) \equiv e^{-\delta_1(n)\bar{T}(s)}\left( N\left[\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}(s)}}{p_1}\right) + (r+\frac{1}{2}\sigma^2)\bar{T}(s)}{\sigma\sqrt{\bar{T}(s)}}\right] - N\left[\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}(s)}}{p_2}\right) + (r+\frac{1}{2}\sigma^2)\bar{T}(s)}{\sigma\sqrt{\bar{T}(s)}}\right]\right), \tag{B62}$$

where $N$ is the standard normal cumulative density function. We can then write the value of the production option under construction, $V^{uc}(\theta,\bar{T}(s),s)$, as the sum of four terms:

$$V^{uc}(\theta,\bar{T}(s),s) = V_1^{uc}(\theta,\bar{T}(s),s) + V_2^{uc}(\theta,\bar{T}(s),s) + V_3^{uc}(\theta,\bar{T}(s),s) + V_4^{uc}(\theta,\bar{T}(s),s), \tag{B63}$$

where:

$$V_1^{uc}(\theta,\bar{T}(s),s) = b_2'\theta^{\beta_2'}\Theta(\theta,\beta_2',\theta^{\diamond},\infty) + b_2\theta^{\beta_2}\Theta(\theta,\beta_2,\theta^{\diamond},\infty) + \frac{\theta}{\delta}\Theta(\theta,1,\theta^{\diamond},\infty) - \frac{(2\gamma+c_2)s+c_1+f}{r}\Theta(\theta,0,\theta^{\diamond},\infty), \tag{B64}$$

$$\begin{aligned}
V_2^{uc}(\theta, \bar{T}(s), s) &= b_1'\theta^{\beta_1'}\Theta(\theta, \beta_1', \theta^P, \theta^\diamond) + b_3'\theta^{\beta_2'}\Theta(\theta, \beta_2', \theta^P, \theta^\diamond) + b_2\theta^{\beta_2}\Theta(\theta, \beta_2, \theta^P, \theta^\diamond) \\
&- \frac{\theta}{\delta + \lambda}\Theta(\theta, 1, \theta^P, \theta^\diamond) + \frac{\theta_A + (2\gamma + c_2)s + c_1}{r + \lambda}\Theta(\theta, 0, \theta^P, \theta^\diamond) \\
&+ \frac{\theta}{\delta}\Theta(\theta, 1, \theta^P, \theta^\diamond) - \frac{(2\gamma + c_2)s + c_1 + f}{r}\Theta(\theta, 0, \theta^P, \theta^\diamond), \qquad \text{(B65)} \\
V_3^{uc}(\theta, \bar{T}(s), s) &= b_4'\theta^{\beta_1'}\Theta(\theta, \beta_1', \theta^D, \theta^P) + b_5'\theta^{\beta_2'}\Theta(\theta, \beta_2', \theta^D, \theta^P) + \frac{\theta_A}{r + \lambda}\Theta(\theta, 0, \theta^D, \theta^P) \\
&+ b_1\theta^{\beta_1}\Theta(\theta, \beta_1, \theta^D, \theta^P) + b_3\theta^{\beta_2}\Theta(\theta, \beta_2, \theta^D, \theta^P) - \frac{f}{r}\Theta(\theta, 0, \theta^D, \theta^P), \qquad \text{(B66)}
\end{aligned}$$

and

$$\begin{aligned}
\bar{V}_4^{uc}(\theta, \bar{T}(s), s) &= b_6'\theta^{\beta_1'}\Theta(\theta, \beta_1', 0, \theta^D) + \frac{\theta_A - f}{r + \lambda}\Theta(\theta, 0, 0, \theta^D) \\
&+ a\theta^{\beta_1}\Theta(\theta, \beta_1, 0, \theta^D) + \frac{\lambda d}{r + \lambda}\Theta(\theta, 0, 0, \theta^D). \qquad \text{(B67)}
\end{aligned}$$

## B.4 Valuing Growth Options

We finally value the growth option allowing the firm to build the production option on output increment $s$ at a unit investment cost of $k$. To do so, denote the value of that growth option by $G(\theta, \bar{T}, s)$ and the demand level at which the firm exercises the growth option by $\theta^*$. We can interpret $\theta^*$ as the optimal investment threshold. Assuming that demand is below the optimal investment threshold, the value of the growth option is equal to:

$$G(\theta, \bar{T}, s) = e\theta^{\beta_1}, \qquad \text{(B68)}$$

where $e$ is a free parameter. In the opposite case, it is equal to:

$$G(\theta, \bar{T}, s) = V^{uc}(\theta, \bar{T}, s) - k. \qquad \text{(B69)}$$

To obtain $a$ and $\theta^*$, we ensure that the value of the production option-under-construction in Equation (B63) value-matches with and also smooth pastes into the value of the growth option in Equation (B68) at the optimal investment threshold:

$$e(\theta^*)^{\beta_1} = V^{uc}(\theta^*, \bar{T}, s) - k, \tag{B70}$$

$$e\beta_1(\theta^*)^{\beta_1 - 1} = \frac{\partial V^{uc}(\theta^*, \bar{T}, s)}{\partial \theta^*}, \tag{B71}$$

where:

$$\frac{\partial V^{uc}(\theta, \bar{T}, s)}{\partial \theta} = \frac{\partial V_1^{uc}(\theta, \bar{T}, s)}{\partial \theta} + \frac{\partial V_2^{uc}(\theta, \bar{T}, s)}{\partial \theta} + \frac{\partial V_3^{uc}(\theta, \bar{T}, s)}{\partial \theta} + \frac{\partial V_4^{uc}(\theta, \bar{T}, s)}{\partial \theta}, \tag{B72}$$

$$\begin{aligned} \frac{\partial V_1^{uc}(\theta, \bar{T}, s)}{\partial \theta} &= b_2' \theta^{\beta_2' - 1} \left( \beta_2' \Theta(\theta, \beta_2', \theta^\diamond, \infty) + Z(\theta, \beta_2', \theta^\diamond, \infty) \right) \\ &+ b_2 \theta^{\beta_2 - 1} \left( \beta_2 \Theta(\theta, \beta_2, \theta^\diamond, \infty) + Z(\theta, \beta_2, \theta^\diamond, \infty) \right) \\ &+ \frac{1}{\delta} \left( \Theta(\theta, 1, \theta^\diamond, \infty) + Z(\theta, 1, \theta^\diamond, \infty) \right) \\ &- \frac{[(2\gamma + c_2)s + c_1] + f}{r} \frac{Z(\theta, 0, \theta^\diamond, \infty)}{\theta}, \end{aligned} \tag{B73}$$

$$\begin{aligned} \frac{\partial V_2^{uc}(\theta, \bar{T}, s)}{\partial \theta} &= b_1' \theta^{\beta_1' - 1} \left( \beta_1' \Theta(\theta, \beta_1', \theta^P, \theta^\diamond) + Z(\theta, \beta_1', \theta^P, \theta^\diamond) \right) \\ &+ b_3' \theta^{\beta_2' - 1} \left( \beta_2' \Theta(\theta, \beta_2', \theta^P, \theta^\diamond) + Z(\theta, \beta_2', \theta^P, \theta^\diamond) \right) \\ &+ b_2 \theta^{\beta_2 - 1} \left( \beta_2 \Theta(\theta, \beta_2, \theta^P, \theta^\diamond) + Z(\theta, \beta_2, \theta^P, \theta^\diamond) \right) \\ &- \frac{1}{\delta + \lambda} \left( \Theta(\theta, 1, \theta^P, \theta^\diamond) + Z(\theta, 1, \theta^P, \theta^\diamond) \right) \\ &+ \frac{[(2\gamma + c_2)s + c_1] + \theta_A}{r + \lambda} \frac{Z(\theta, 0, \theta^P, \theta^\diamond)}{\theta} \\ &+ \frac{1}{\delta} \left( \Theta(\theta, 1, \theta^P, \theta^\diamond) + Z(\theta, 1, \theta^P, \theta^\diamond) \right) \\ &- \frac{[(2\gamma + c_2)s + c_1] + f}{r} \frac{Z(\theta, 0, \theta^P, \theta^\diamond)}{\theta}, \end{aligned} \tag{B74}$$

$$
\begin{aligned}
\frac{\partial V_3^{uc}(\theta,\bar{T},s)}{\partial\theta} &= b_4'\theta^{\beta_1'-1}\left(\beta_1'\Theta(\theta,\beta_1',\theta^D,\theta^P)+Z(\theta,\beta_1',\theta^D,\theta^P)\right)\\
&+ b_5'\theta^{\beta_2'-1}\left(\beta_2'\Theta(\theta,\beta_2',\theta^D,\theta^P)+Z(\theta,\beta_2',\theta^D,\theta^P)\right)\\
&+ \left(\frac{\theta_A}{r+\lambda}-\frac{f}{r}\right)\frac{Z(\theta,0,\theta^D,\theta^P)}{\theta}\\
&+ b_1\theta^{\beta_1-1}\left(\beta_1\Theta(\theta,\beta_1,\theta^D,\theta^P)+Z(\theta,\beta_1,\theta^D,\theta^P)\right)\\
&+ b_3\theta^{\beta_2-1}\left(\beta_2\Theta(\theta,\beta_2,\theta^D,\theta^P)+Z(\theta,\beta_2,\theta^D,\theta^P)\right),
\end{aligned} \tag{B75}
$$

$$
\begin{aligned}
\frac{\partial V_4^{uc}(\theta,\bar{T},s)}{\partial\theta} &= b_6'\theta^{\beta_1'-1}\left(\beta_1'\Theta(\theta,\beta_1',0,\theta^D)+Z(\theta,\beta_1',0,\theta^D)\right)\\
&+ \left(\frac{(\theta_A-f)+\lambda d}{r+\lambda}\right)\frac{Z(\theta,0,0,\theta^D)}{\theta}\\
&+ a\theta^{\beta_1-1}\left(\beta_1\Theta(\theta,\beta_1,0,\theta^D)+Z(\theta,\beta_1,0,\theta^D)\right),
\end{aligned} \tag{B76}
$$

and

$$
Z(\theta,n,p_1,p_2)\equiv\frac{e^{-\delta_1(n)\bar{T}}}{\sigma\sqrt{\bar{T}}}\left(\phi\left[\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}}}{p_1}\right)+(r+\frac{1}{2}\sigma^2)\bar{T}}{\sigma\sqrt{\bar{T}}}\right]-\phi\left[\frac{\ln\left(\frac{\theta e^{-\delta_2(n)\bar{T}}}{p_2}\right)+(r+\frac{1}{2}\sigma^2)\bar{T}}{\sigma\sqrt{\bar{T}}}\right]\right), \tag{B77}
$$

where $\phi$ is the standard normal probability density function. Since it is impossible to analytically solve Equations (B70) and (B71) for $e$ and $\theta^*$, we do so numerically.

## B.5 Determining a Firm's Optimal Capacity

Given demand $\theta$, we define a firm's optimal capacity $K^*$ as that $s$ value satisfying:

$$
V^{uc}(\theta,\bar{T},K^*)=k+G(\theta,\bar{T},K^*), \tag{B78}
$$

ensuring that the marginal benefit from exercising the growth option on output increment $s$ (which is obtaining the equivalent under-production option) is identical to the marginal cost from doing so (which is paying the investment cost and sacrificing the growth option).