# Real Options Models of the Firm, Capacity Overhang, and the Cross Section of Stock Returns

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## ABSTRACT

We use a stochastic frontier model to obtain a stock-level estimate of the difference between a firm's installed production capacity and its optimal capacity. We show that this "capacity overhang" estimate relates significantly negatively to the cross section of stock returns, even when controlling for popular pricing factors. The negative relation persists among small and large stocks, stocks with more or less reversible investments, and in good and bad economic states. Capacity overhang helps explain momentum and profitability anomalies, but not value and investment anomalies. Our evidence supports real options models of the firm featuring valuable divestment options.

RECENT STUDIES USE REAL OPTIONS THEORY to establish links between a firm's capacity-related decisions, systematic risk, and characteristics. Focusing on a firm that owns both installed production capacity and costly-to-reverse growth options, a common result in these studies is that the firm's expected return depends on the difference between its installed capacity and the level of capacity that maximizes firm value net of capacity installation costs

("capacity overhang").[1,2] There is disagreement, however, about the exact nature of the expected return-capacity overhang relation. For example, assuming highly irreversible but cheap-to-exercise growth options, Carlson, Fisher, and Giammarino (2004), Zhang (2005), and Cooper (2006) predict a mostly positive relation, potentially explaining value and investment anomalies in stock returns. Assuming more reversible growth options, Sagi and Seasholes (2007), Guthrie (2011), and Hackbarth and Johnson (2015) predict a negative relation, potentially explaining momentum and profitability anomalies. Combining low investment reversibility with expensive-to-exercise growth options, Hackbarth and Johnson (2015) show that the relation can also be U-shaped, potentially explaining both groups of anomalies above.[3]

Given the strong theoretical foundations underlying the expected return-capacity overhang relation, there is surprisingly little empirical research on the shape of the relation and its implications for stock anomalies. The lack of empirical research probably reflects the difficulty in estimating stock-level capacity overhang. We make an effort to close this gap in the literature. We employ a stochastic frontier model to estimate stock-level capacity overhang. Using the model's estimates, we run portfolio sorts and Fama-Macbeth (FM) (1973) regressions to study the shape of the stock return-capacity overhang relation. We also run horse races between the capacity overhang estimate and value, momentum, investment, and profitability variables, which allows us to study whether capacity overhang helps explain these anomalies.

We start with a theoretical analysis of a version of Pindyck's (1988) real options model of a firm that allows for costly investment reversibility. We show that this standard demand-based real options model is able to produce the different expected return-capacity overhang relations established in earlier work. More importantly, we also gain insights that inform our empirical estimation of capacity overhang from the model. The model considers a firm that sells output at a stochastic price. The firm maximizes value by taking costless production (i.e., capacity utilization) decisions and capacity adjustment (i.e.,

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[1] Assuming that the cost of a capacity unit does not depend on installed capacity, we can intuitively think of the capacity level that maximizes net firm value ("optimal capacity") as the initial capacity chosen by a start-up firm with the same values for the state variable and the model parameters. Firms sometimes build up capacity in excess of this level because capacity installation costs exceed the resale value of capacity, creating a wedge between the value of the state variable at which the firm invests and the value at which it divests.

[2] We note that capacity overhang is related, but not identical to, "excess capacity," which is usually defined as the proportion of a firm's installed capacity used in production. We focus on capacity overhang because first, it is a more fundamental concept than excess capacity (i.e., capacity overhang determines excess capacity, but not necessarily vice versa), and second, our stochastic frontier model approach allows us to estimate capacity overhang, but not excess capacity.

[3] Value anomalies describe the tendency of value stocks to have higher returns than growth stocks. Investment anomalies describe the tendency of noninvesting (or divesting) stocks to have higher returns than investing stocks. Momentum anomalies describe the tendency of high intermediate-term past return stocks (winners) to have higher returns than low intermediate-term past return stocks (losers). Profitability anomalies describe the tendency of profitable stocks to have higher returns than unprofitable stocks.

investment and divestment) decisions under fixed capacity purchase and sale prices. In the absence of capacity adjustment options, the model produces a positive expected return-capacity overhang relation. This occurs because a firm with sufficiently high-capacity overhang produces below full capacity. Thus, such a firm is able to increase (decrease) its capacity utilization rate as the output price increases (decreases), which renders its profits more sensitive to changes in the output price.

Endowing the firm with capacity adjustment options changes the expected return-capacity overhang relation. Growth options enable an optimal-capacity firm to invest and further increase profits as the output price rises, increasing the firm's expected return, while divestment options enable a high-capacity-overhang firm to divest and mitigate falling profits as the output price drops, lowering the firm's expected return. Thus, when we introduce growth options, the expected return-capacity overhang relation can become U-shaped, and when we introduce both growth and divestment options, the relation can become negative.

In our empirical work, we employ a novel approach to estimating stock-level capacity overhang, namely, a stochastic frontier model. The stochastic frontier model decomposes installed production capacity into an optimal capacity term and a capacity overhang term, identifying the two terms using different determinants and appropriate distributional assumptions. The most important distributional assumption is that capacity overhang cannot be negative. In our main specification, we use a firm's property, plant, and equipment (PPE) plus intangible assets to proxy for installed production capacity. Informed by the real options model, we specify optimal capacity as a function of sales, operating and nonoperating costs, volatility, systematic risk, and the risk-free rate of return. We include industry fixed effects to capture unobservable optimal capacity determinants (e.g., investment costs). Also informed by the real options model, we specify capacity overhang as a function of variables reflecting past decreases in a firm's demand. We estimate the model recursively, which ensures that the capacity overhang estimate could have been computed in real time. Validation tests suggest that the capacity overhang estimate captures time-series and cross-sectional variation in stock-level investment behavior and industry-level capacity utilization rates obtained from surveys.

We next form value-weighted portfolios sorted on estimated capacity overhang to study the stock return-capacity overhang relation. Mean excess returns decline almost monotonically over the portfolios, with a spread across the extreme portfolios of –12.5% per annum (*t*-statistic: –4.20). Adjusting for risk using the CAPM, Hou, Xue, and Zhang's (2015) *Q*-theory model, or Fama-French's (2015) five-factor model, we find that the spread return attracts a negative and strongly significant loading on the profitability factors in the *Q*-theory and five-factor models, which helps explain the mean spread return. In contrast, the spread return loads positively, although less significantly, on all other factors in the models. Thus, the spread portfolio alphas do not differ much from the spread portfolio mean excess return. Similarly, FM regressions of single-stock returns on the capacity overhang estimate and the joint set

of firm characteristics underlying the CAPM, the *Q*-theory model, and the five-factor model also produce significant negative capacity overhang premia, with *t*-statistics consistently below –3.

We run several robustness tests on the stock return-capacity overhang relation. We first repeat the portfolio sorts by market size subsamples to alleviate concerns that our results are driven by micro stocks. We next repeat the portfolio sorts by investment reversibility subsamples to test the real options model prediction that lower investment reversibility produces a less negative or U-shaped expected return-capacity overhang relation. Finally, we examine the capacity overhang portfolios separately in good and bad economic states to test the hypothesis that, if the expected return-capacity overhang relation is U-shaped, the positive part of the relation is more likely to materialize in bad states with high-capacity overhang. The robustness tests corroborate our result that the stock return-capacity overhang relation is negative.

Our pricing results are most consistent with real options models in which the firm owns valuable divestment options, which cause the expected return to decline with capacity overhang. Prior theoretical work suggests that such models have the potential to explain momentum and profitability anomalies. This is because past returns and profitability are likely negatively related to capacity overhang, which suggests that profitable winner stocks have lower capacity overhang and thus higher returns than unprofitable loser stocks, as is the case. Conversely, such models do not have the potential to explain value and investment anomalies. This is because value variables (investment rates) are likely positively (negatively) related to capacity overhang, which suggests that investing growth stocks have lower capacity overhang and thus higher returns than noninvesting (or divesting) value stocks, as is not the case.

We next run formal tests of the ability of capacity overhang to explain stock anomalies. To do so, we perform horse races between estimated capacity overhang and 20 well-known value, momentum, investment, and profitability anomaly variables from prior studies. The horse races confirm that capacity overhang helps explain momentum and profitability anomalies, but not value and investment anomalies. Controlling for capacity overhang reduces Jegadeesh and Titman's (1993) 6- and 11-month past return (momentum) premia by 30% to 40%, although only the six-month past return premium becomes insignificant. That capacity overhang does not completely eliminate momentum anomalies is consistent with Asness, Moskowitz, and Pedersen's (2013) observation that real options models cannot be the entire explanation for such anomalies. Crucially, however, our results suggest that real options models significantly contribute to such an explanation. Controlling for capacity overhang also greatly reduces profitability premia. For example, it eliminates Novy-Marx's (2013) gross profitability premium and Fama and French's (2015) total profitability premium, but not Hou, Xue, and Zhang's (2015) return-on-equity (ROE) premium. Conversely, controlling for capacity overhang has only marginal effects on Fama and French's (1992) book-to-market premium or Titman, Wei, and Xie's (2004) and Cooper, Gulen, and Schill's (2008) investment

premia, while it reinforces DeBondt and Thaler's (1985) long-term reversal premia.

A possible caveat with respect to our empirical analysis is that capacity adjustment costs excluded from our theoretical work, such as convex or fixed adjustment costs, may reduce the suitability of stochastic frontier models to estimate capacity overhang. In the presence of fixed adjustment costs, firms invest only when the investment-induced increase in firm value net of linear costs covers the fixed costs. In this case, two firms with the same values for the optimal capacity determinants and with values for the capacity overhang determinants that signal little or no capacity overhang can have a (slightly) different installed capacity. Since the stochastic frontier model is unable to explain such difference using either set of determinants, the difference ends up in the optimal capacity residual, which renders our capacity overhang estimate less accurate but does not invalidate it. In the presence of convex adjustment costs, a firm's adjustments toward optimal capacity depend on the entire history of the firm's state variable values. While it would be challenging to model this dependence, Cooper and Haltiwanger (2006) and Bloom (2009) find that convex adjustment costs are negligible relative to linear, fixed, and investment-irreversibility-induced adjustment costs. Thus, convex costs are unlikely to greatly distort the ability of stochastic frontier models to estimate capacity overhang.

Our paper contributes to the real options asset pricing literature, as pioneered by the theoretical work of Berk, Green, and Naik (1999) and Gomes, Kogan, and Zhang (2003). Cooper, Wu, and Gerard (2005) use capacity utilization rates obtained from surveys to proxy for industry-level capacity overhang, and report that capacity overhang positively prices the cross section of industry returns. Cooper and Priestley (2009) use detrended industrial production to proxy for capacity overhang, and report that capacity overhang positively predicts the time series of market returns. In contrast, our stock-level tests suggest a negative expected return-capacity overhang relation. Garcia-Feijóo and Jorgensen (2010) and Novy-Marx (2011) use operating leverage to proxy for capacity overhang, and report that capacity overhang positively prices the cross section of stock returns. In contrast, our more direct proxy for capacity overhang suggests a negative relation. Using a calibration of a real options model to study the expected return-capacity overhang relation, Hackbarth and Johnson (2015) also find a negative relation. Our work complements theirs by using more standard asset pricing tests facilitated by our new proxy for capacity overhang. Using our proxy, we are able to incorporate cross-sectional variation in firm parameters (e.g., in demand volatility) into our empirical analysis.

Our work is also relevant for studies testing real options model predictions for the effect of investment on stock returns. Anderson and Garcia-Feijóo (2006) show that growth stocks invest more than value stocks, which supports Berk, Green, and Naik's (1999) prediction that the optimal exercise of low-risk growth options decreases both the expected return and the book-to-market ratio. Anderson and Garcia-Feijóo (2006) and Xing (2008) report that investment

variables are negatively priced in the cross section of stock returns and help explain the value anomaly. Lyandres, Sun, and Zhang (2008) show that controlling for investment behavior explains a large fraction of initial public offering (IPO) and secondary public offering (SEO) underpricing, consistent with Carlson, Fisher, and Giammarino's (2006) real options model predictions. Cooper and Priestley (2011) show that the negative pricing of the investment variables is linked to systematic risks. Interestingly, our capacity overhang estimate has a close-to-zero correlation with the above investment variables.

We also make a theoretical contribution to the real options asset pricing literature. Prior theoretical work often claims that fixed production costs underlying operating leverage are necessary to generate a positive expected return-capacity overhang relation. We show that allowing firms to adjust capacity utilization can act as a substitute for fixed production costs in creating a positive relation. Notwithstanding, similar mechanisms complement the operating leverage effects in the models of Carlson, Fisher, and Giammarino (2004) and Cooper, Wu, and Gerard (2005), although the mechanisms are not explicitly discussed by these authors.

Finally, we are the first to use stochastic frontier models in asset pricing research. Such models are slowly becoming more popular in finance. For instance, Hunt-McCool and Warren (1993), Hunt-McCool, Koh, and Francis (1996), and Habib and Ljungqvist (2005) use them to estimate earnings efficiency, IPO underpricing, and the agency cost of equity, respectively.

The remainder of the paper is organized as follows. In Section I, we theoretically examine the expected return-capacity overhang relation. In Section II, we use a stochastic frontier model to obtain a stock-level estimate of capacity overhang. We next use the capacity overhang estimate to study the stock return-capacity overhang relation and to assess whether capacity overhang helps explain well-known stock anomalies. Section III concludes.

## I. Theoretical Analysis

In this section, we investigate the expected return-capacity overhang relation in an extension of Pindyck's (1988) demand-based real options model of a firm, allowing for costly investment reversibility. We show that the model is able to predict a positive, negative, or U-shaped relation despite it not including fixed production costs. We also gain insights that inform our empirical estimation of capacity overhang from the model.

### A. Model Setup

Consider a monopolistic all-equity firm with an infinite horizon. The firm continuously makes production decisions and capacity adjustment decisions to maximize value. At each time $t \in [0, +\infty)$, the firm uses installed capacity to produce and instantaneously sell some quantity of output. The firm's installed production capacity, $\bar{K} \in \{0, +\infty\}$, is the firm's number of production units at

time $t$, with each unit able to produce one unit of output per unit of time.[4] Accordingly, the firm's output quantity per unit of time at time $t$ is $Q \in \{0, \bar{K}\}$.

Output is sold at a price $P$ driven by the downward-sloping demand curve $P = \theta - \gamma Q$, where $\theta$ is stochastic demand and $\gamma$ is the (constant) elasticity of demand. In the main analysis, stochastic demand obeys a Geometric Brownian motion (GBM),

$$d\theta = \alpha\theta dt + \sigma\theta dW, \tag{1}$$

where $\alpha > 0$ and $\sigma > 0$ are constants and $W$ is a Brownian motion. The output cost function per unit of time is exponentially increasing and given by $C(Q) = c_1 Q + \frac{1}{2}c_2 Q^2$, where $c_1 \geq 0$ and $c_2 \geq 0$ are constants. The firm's time $t$ profit per unit of time, $\pi(\theta, Q)$, is then

$$\pi(\theta, Q) = PQ - c_1 Q - \frac{1}{2}c_2 Q^2 = \theta Q - \gamma Q^2 - c_1 Q - \frac{1}{2}c_2 Q^2. \tag{2}$$

Since adjusting output quantity is costless, the firm maximizes profit and the value of the installed capacity by setting output quantity to $\min(\frac{\theta - c_1}{2\gamma + c_2}, \bar{K})$ at each time $t$.

In addition to adjusting its output quantity, the firm is also able to adjust its installed production capacity at each time $t$. Denote by $k > 0$ the investment cost of installing one unit of capacity, and by $d \geq 0$, the divestment proceeds realized by selling one unit of capacity, where $k - d \geq 0$. There is no adjustment time, and capacity can be installed and sold without restriction. To maximize value, the firm invests when the value of new capacity exceeds the sum of the investment cost and the value of the option to install that capacity later. Similarly, the firm divests when the value of installed capacity is less than the sum of the divestment proceeds and the value of the option acquired to repurchase that capacity later.

We define the optimal capacity level, $K^*$, as the value of capacity that maximizes the total value of installed capacity plus growth options minus the total installation cost ($k\bar{K}$). Capacity overhang is the difference between installed capacity, $\bar{K}$, and optimal capacity, $K^*$. Since we abstract from fixed investment costs and time-to-build, if the firm's installed capacity is below optimal capacity, the firm instantaneously raises its installed capacity to optimal capacity. Thus, capacity overhang is truncated from below at zero. Conversely, since costly investment reversibility implies that investment costs exceed divestment proceeds ($k > d$), the firm only divests capacity overhang in excess of some positive threshold value driven by demand and model parameters, most importantly, the divestment proceeds $d$. Crucially, since the threshold value increases to infinity as demand increases to infinity, capacity overhang is not truncated from above. Fixing installed capacity, capacity overhang increases as demand decreases. Fixing demand, capacity overhang increases as installed capacity increases.

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[4] We define a unit of time as a one-unit increase in the time index $t$.

Pindyck (1988) suggests interpreting the described firm as a portfolio of incremental options to produce and grow. Each incremental option to produce consists of an American call option yielding a payoff of $\max(\theta - (2\gamma + c_2)K - c_1, 0)$ per unit of time at time $t$ and a perpetual American put option allowing the firm to divest the option to produce at a unit price of $d$. Upon divestment, the incremental option to produce turns into the corresponding incremental option to grow. Each incremental option to grow is a perpetual American call option that allows the firm to purchase the corresponding option to produce at a unit price of $k$. Upon exercise, the incremental option to grow turns into the corresponding incremental option to produce. Denoting the value of the option to produce indexed by $\theta$ and $K$ as $\Delta V(\theta, K)$ and the value of the option to grow indexed by $\theta$ and $K$ as $\Delta F(\theta, K)$, we can write firm value, $W$, as

$$W = \int_0^{\bar{K}} \Delta V(\theta, K)dK + \int_{\bar{K}}^{\infty} \Delta F(\theta, K)dK. \tag{3}$$

Consistent with interpreting the firm as a portfolio of real options, the firm's expected excess return, $E[r_A] - r$, can be written as the expected excess return of the portfolio of real options owned by the firm. Exploiting the fact that an option's expected excess return is equal to the product of the option's elasticity and the expected excess return of the underlying asset (see Cox and Rubinstein (1985, p. 186)), equation (4) links the firm's expected excess return to the elasticities of the real options owned by the firm:

$$\mathrm{E}[r_A] - r = \left( \int_0^{\bar{K}} \frac{\Delta V(\theta, K)}{W} \Omega_{V(\theta, K)} dK + \int_{\bar{K}}^{\infty} \frac{\Delta F(\theta, K)}{W} \Omega_{F(\theta, K)} dK \right)(\mu - r), \quad (4)$$

where $\mathrm{E}[r_A]$ is the expected firm return, $\mu$ the expected return of a demand-mimicking portfolio, $r$ the risk-free rate of return, $\Omega_{V(\theta, K)}$ the elasticity of the option to produce, and $\Omega_{F(\theta, K)}$ the elasticity of the option to grow. An option's elasticity is defined as the partial derivative of the option's value with respect to demand times the ratio of demand to option value.

Our model is similar to most real options asset pricing models cited in the introduction in allowing for linear investment costs and costly investment reversibility. However, similar to only Carlson, Fisher, and Giammarino (2004) and Cooper, Wu, and Gerard (2005), the model also allows for variable production costs and capacity utilization choice. Similar to only Sagi and Seasholes (2007) and Aguerrevere (2009), the model further allows for mean reversion in demand and Cournot competition among identical firms in the Internet Appendix.[5] Unlike most other models, our model does not feature fixed production costs. While it would be easy to include such costs, we avoid doing so to stress that the expected return-capacity overhang relation produced by our model is not driven by operating leverage caused by fixed production costs. Finally, our model ignores both convex and fixed (or quasi-fixed) capacity

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[5] The Internet Appendix is available in the online version of the article at the *Journal of Finance* website.

adjustment costs. The theoretical work of Carlson, Fisher, and Giammarino (2004), Cooper (2006), and Hackbarth and Johnson (2015) suggests that including fixed adjustment costs does not produce asset pricing conclusions greatly different from those produced by our model, and the empirical work of Cooper and Haltiwanger (2006) and Bloom (2009) shows that convex adjustment costs are negligible compared to linear, fixed, and investment-irreversibility-induced adjustment costs.

## B. Model Solution

Appendix A shows that the value of the production option indexed by $\theta$ and $K$ is

$$\Delta V(\theta, K) = \begin{cases} \Delta F(\theta, K) + d; & \theta \leq \theta' \\ b_1\theta^{\beta_1} + b_3\theta^{\beta_2}; & \theta' \leq \theta \leq (2\gamma + c_2)K + c_1 \\ b_2\theta^{\beta_2} + \theta/\delta - [(2\gamma + c_2)K + c_1]/r; & \theta \geq (2\gamma + c_2)K + c_1, \end{cases}$$
(5)

where $\beta_1$, $\beta_2$, $b_1$, $b_2$, $b_3$, and $\theta'$ are constants defined in the Appendix and $\delta \equiv \mu - \alpha$. The component solutions can be interpreted as follows. If demand is below $\theta'$, the firm sells the option to produce, realizes divestment proceeds $d$, and acquires an option to repurchase the option to produce at a later date. If demand lies between $\theta'$ and $(2\gamma + c_2)K + c_1$, the firm retains the option to produce but does not use it, and thus its value derives from the options to use the option to produce if demand rises ($b_1\theta^{\beta_1}$) and to sell it if demand drops ($b_3\theta^{\beta_2}$). If demand is above $(2\gamma + c_2)K + c_1$, the firm uses the option to produce, and thus its value derives from the option to stop using the option to produce if demand drops ($b_2\theta^{\beta_2}$) and the cash flows arising from perpetually using the option to produce ($\theta/\delta - [(2\gamma + c_2)K + c_1]/r$).

Appendix A also shows that the value of the growth option indexed by $\theta$ and $K$ is

$$\Delta F(\theta, K) = \begin{cases} a\theta^{\beta_1}; & \theta \leq \theta^* \\ \Delta V(\theta, K) - k; & \theta \geq \theta^*, \end{cases}$$
(6)

where $a$ and $\theta^*$ are constants defined in the Appendix. The component solutions can be interpreted as follows. If demand is below $\theta^*$, the firm waits to exercise the growth option. The option's value thus derives from the possibility of a later exercise ($a\theta^{\beta_1}$). If demand is above $\theta^*$, the firm exercises the growth option, in which case the option's value is equal to the value of the corresponding option to produce minus the investment cost $k$.

The model solutions imply that the elasticity of a "used" option to produce (satisfying $K \leq (\theta - c_1)/(2\gamma + c_2)$) is $(b_2\beta_2\theta^{\beta_2} + \theta/\delta)/\Delta V(\theta, K)$, while the elasticity of an "idle" option to produce (satisfying $K \geq (\theta - c_1)/(2\gamma + c_2)$) is $(b_1\beta_1\theta^{\beta_1} + b_3\beta_2\theta^{\beta_2})/\Delta V(\theta, K)$. In contrast, the elasticity of a growth option is always $\beta_1$. Assuming that divestment proceeds $d$ are zero and investments are

completely irreversible, the elasticities of idle options to produce and of growth options become $\beta_1$, while the elasticities of used options to produce lie below $\beta_1$ (see Appendix A and Lemma 2 in Appendix B). Thus, in contrast to most other real options asset pricing models studied in the literature, allowing for capacity utilization choice enables our model to generate options to produce that are as risky as growth options.[6]

Appendix A also shows that the optimal exercise level $\theta^*$ satisfies the equation

$$b_2 \left( \frac{\beta_1 - \beta_2}{\beta_1} \right) (\theta^*)^{\beta_2} + \left( \frac{\beta_1 - 1}{\beta_1} \right) \frac{\theta^*}{\delta} - \frac{(2\gamma + c_2)K + c_1}{r} - k = 0, \qquad (7)$$

which also defines the optimal installed capacity level $K^*$ for each demand level $\theta$. Numerical analysis of equation (7) reveals intuitive results: optimal capacity $K^*$ increases with demand ($\theta$) and divestment proceeds ($d$), it decreases with explicit and implicit production costs ($c_1$, $c_2$, and $\gamma$), demand volatility ($\sigma$), systematic risk ($\mu$), and the capacity installation cost ($k$), and it has an ambiguous relation with the risk-free rate of return ($r$).

### C. Model Conclusions

#### C.1. Irreversible Investments

Assuming zero divestment proceeds, investments are completely irreversible and the model collapses to Pindyck's (1988) model. Proposition 1 summarizes a firm's expected return-capacity overhang relation conditional on capacity utilization for this case.

PROPOSITION 1: *Assuming zero divestment proceeds ($d = 0$), consider a firm optimally using its entire installed capacity to produce output (i.e., a firm operating at a 100% capacity utilization rate and satisfying $\bar{K} \leq (\theta - c_1)/(2\gamma + c_2)$). The effect on the firm's expected excess return, $\mathrm{E}[r_A] - r$, of an increase in capacity overhang induced by an increase in installed capacity ($\bar{K}$) is given by*

$$\frac{\partial \mathrm{E}[r_A] - r}{\partial \bar{K}} = \left( \frac{\Delta V(\theta, \bar{K})}{W} \left( \frac{b_2 \beta_2 \theta^{\beta_2} + \theta/\delta}{\Delta V(\theta, \bar{K})} - (\mathrm{E}[r_A] - r) \right) \right.$$
$$\left. - \frac{\Delta F(\theta, \bar{K})}{W} \left( \beta_1 - (\mathrm{E}[r_A] - r) \right) \right) (\mu - r). \qquad (8)$$

*The partial derivative in equation (8) can be positive, zero, or negative.*

*Now consider a firm that uses less than its entire installed capacity to produce output (i.e., a firm operating at a capacity utilization rate below 100%*

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[6] Sagi and Seasholes (2007) and Kogan and Papanikolaou (2013, 2014) show that to generate production options that are as risky or even riskier than growth options, one may alternatively assign a finite maturity date to the growth options or allow for stochastic variation in investment costs, respectively.
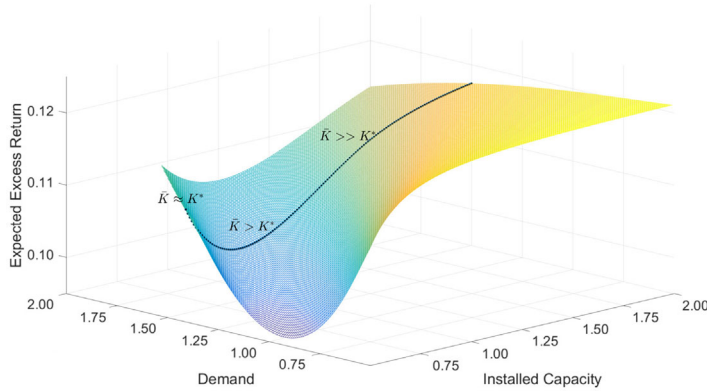
**Figure 1. Expected return-capacity overhang relation under no reversibility.** The figure plots a firm's expected excess return, $\mathrm{E}[r_A] - r$, against demand, $\theta$, and installed capacity, $\bar{K}$. Keeping the value of demand fixed, optimal capacity, $K^*$, is given by the lowest available value on the installed capacity axis. The demand drift rate ($\alpha$) and volatility ($\sigma$) are 0.05 and 0.10, respectively. The demand elasticity ($\gamma$) is 0.50. The cost parameters ($c_1$ and $c_2$) are zero. The purchase price of capital ($k$) is 10; the resale price ($d$) is zero. The expected return of the demand mimicking portfolio ($\mu$) is 0.10. The risk-free rate ($r$) is 0.04. (Color figure can be viewed at wileyonlinelibrary.com)

*and satisfying $\bar{K} > (\theta - c_1)/(2\gamma + c_2)$). The effect on the firm's expected excess return, $\mathrm{E}[r_A] - r$, of an increase in capacity overhang induced by an increase in installed capacity ($\bar{K}$) is given by*

$$\frac{\partial \mathrm{E}[r_A] - r}{\partial \bar{K}} = \left( \left( \frac{\Delta V(\theta, \bar{K})}{W} - \frac{\Delta F(\theta, \bar{K})}{W} \right) (\beta_1 - (\mathrm{E}[r_A] - r)) \right) (\mu - r). \quad (9)$$

*The partial derivative in equation (9) is strictly positive.*

PROOF: See Appendix B. ∎

Figure 1 illustrates Proposition 1, plotting the expected excess return, $\mathrm{E}[r_A] - r$, against demand, $\theta$, and installed capacity, $\bar{K}$. Given demand, optimal capacity, $K^*$, is given by the lowest available value on the installed capacity axis; see the left end point of the highlighted U-curve in the surface. When installed capacity is at or close to optimal capacity ($\bar{K} \approx K^*$ in the figure), the firm can be interpreted as a portfolio of low-risk *used* production options and high-risk growth options, leading the expected return to be at an intermediate level given by the left end point of the U-curve. Holding demand constant and increasing installed capacity to a slightly higher level ($\bar{K} > K^*$), the value of the growth options declines and the firm's real options portfolio is rebalanced toward low-risk *used* options to produce. Thus, the expected return declines. However, increasing installed capacity further ($\bar{K} >> K^*$), the firm starts to reduce capacity utilization below 100%. As this happens, the firm's real options portfolio is rebalanced toward high-risk *idle* production options and away from low-risk *used* production options, which increases the expected return.

Thus, in accordance with Proposition 1, Figure 1 shows that the effect of an increase in capacity overhang on the expected return depends on the level of capacity overhang. When capacity overhang is low or intermediate (i.e., when equation (8) holds), the marginal effect of an increase in capacity overhang on the expected return is ambiguous. However, when capacity overhang is high (i.e., when equation (9) holds), the marginal effect on the expected return is unambiguously positive.[7]

The results in Proposition 1 are relevant for the literature in two ways. First, prior studies suggest that operating leverage resulting from fixed production costs is necessary to produce a positive expected return-capacity overhang relation. Our model features no fixed production costs and thus produces no operating leverage. Despite that, the proposition reveals that the model can produce a positive expected return-capacity overhang relation. This happens because the model treats a firm's installed capacity as a portfolio of *options* to produce, with the risk of these options decreasing with demand but increasing with option leverage.[8]

The results in Proposition 1 are also relevant for the ability of real options models to explain stock anomalies. Carlson, Fisher, and Giammarino (2004), Zhang (2005), and Cooper (2006) show that real options models similar to the model in this section can produce a (mostly) positive expected return-capacity overhang relation. Since in these models, capacity overhang is positively related to value variables (e.g., the book-to-market ratio), but negatively related to investment rates, such models have the potential to explain value and investment anomalies. However, similar to Hackbarth and Johnson (2015), our analysis suggests that the expected return-capacity overhang relation is only (mostly) positive if the effect of growth options on the expected return is sufficiently small at low to intermediate levels of capacity overhang. One way to ensure this is to choose model parameters reducing the values or elasticities of growth options. To see this, Figure 2 plots the expected return against installed capacity, varying either investment costs ($k$) or demand volatility ($\sigma$). The figure shows that lowering investment costs (reducing the elasticities of growth options) or demand volatility (reducing both their elasticities and values) renders the relation between expected return and installed capacity, and

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[7] We could alternatively fix installed capacity and let demand decrease from the optimal threshold $\theta^*$ to zero. Since $\theta - \theta^*$ contains the same information about capacity overhang as $\bar{K} - K^*$, doing so would also yield the conclusion that a decline in demand causing an increase in capacity overhang decreases the expected return when demand is close to $\theta^*$, but increases the expected return when demand is further away.

[8] The result that capacity utilization choice can substitute for fixed production costs in producing a positive expected return-capacity overhang relation is not special to our demand function. As the proof of Proposition 1 shows, the result holds as long as (i) the marginal option to produce is worth more than the marginal option to grow, and (ii) the marginal option to produce is as risky as (or riskier than) the marginal option to grow. Standard arbitrage arguments imply that condition (i) always holds; see the proof of Lemma 1 in Appendix B. Condition (ii) holds as long as both the value of an idle option to produce and the value of an option to grow are given by $b\theta^{\beta_1}$, with $b$ some constant. For example, it is easy to show that condition (ii) holds under the multiplicative (isoelastic) demand function $P = \theta Q^{-1/\gamma}$.
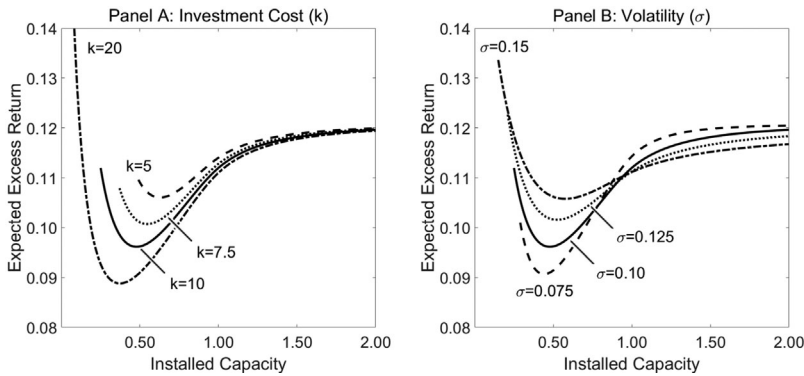
**Figure 2. Comparative statics for the expected return-capacity overhang relation under no reversibility.** The figure plots a firm's expected excess return, $E[r_A] - r$, against installed capacity, $\bar{K}$, varying the unit purchase price of capital ($k$) from 5 to 20 (Panel A) and demand volatility ($\sigma$) from 0.075 to 0.15 (Panel B). Optimal installed capacity, $K^*$, is the value of installed capacity associated with the left end point of each curve. Demand ($\theta$) is one. The base-case parameter values are as in Figure 1.

thus capacity overhang, closer to monotonically positive. It is in this spirit that Zhang (2005, p. 68) concludes that investing must be "relatively easy" for models with no or highly costly investment reversibility to explain value and investment anomalies.

### C.2. Costly Investment Reversibility

Section I.C.1 shows that our model produces a mostly positive or U-shaped expected return-capacity overhang relation when investments are completely irreversible. We now show that when investments are reversible, the model can also produce a negative relation. To this end, Figure 3 plots the expected return against demand and installed capacity, using the same parameter values as in Figure 1 except that we now allow capacity to be sold at a divestment price of five (i.e., $d = 5$). Holding demand constant, the figure suggests that, in this case, the expected return mostly declines with installed capacity. For example, considering the line highlighted in the surface, the expected return monotonically declines from 10.3% to 8.7%. The reason is that allowing for costly investment reversibility is equivalent to endowing a firm with options to sell installed capacity. Since the values of these options decline with demand, the options have a negative elasticity. The negative elasticity lowers the expected return, especially when divestment options are most valuable—at high-capacity overhang levels.

Our results in this section align with those in Sagi and Seasholes (2007), Guthrie (2011), and Hackbarth and Johnson (2015), who study models similar to ours. Since real options models predict capacity overhang to be negatively related to past returns and profitability, real options models with reversible investments could explain momentum and profitability anomalies.
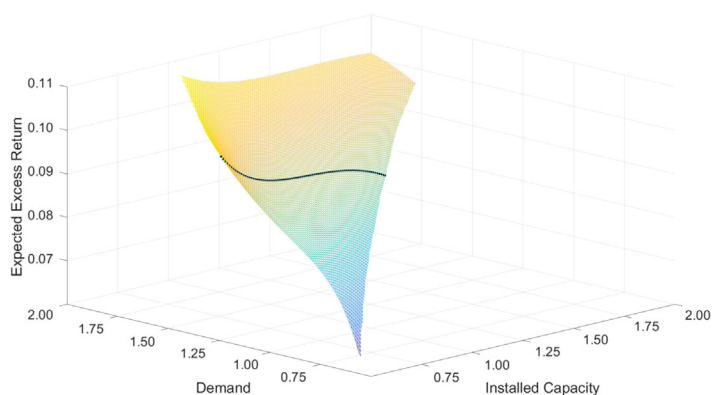
**Figure 3. Expected return-capacity overhang relation under costly reversibility.** The figure plots a firm's expected excess return, $\mathrm{E}[r_A] - r$, against demand, $\theta$, and installed capacity, $\bar{K}$. Keeping the value of demand fixed, optimal capacity, $K^*$, is given by the lowest available value on the installed capacity axis, while the optimal divestment capacity value is given by the highest available value. The resale price of capital ($d$) is five. Other parameter values are the same as in Figure 1. (Color figure can be viewed at wileyonlinelibrary.com)

## C.3. Other Extensions

In our Internet Appendix, we examine two extensions of the model in this part of the paper. In line with Aguerrevere (2009), we first study the implications of allowing for Cournot competition among identical firms. We find that such competition does not affect the shape of the expected return-capacity overhang relation. Second, in line with Sagi and Seasholes (2007), we study the implications of using a mean-reverting square root process to model demand. We find that more mean reversion results in the expected return-capacity overhang relation being closer to monotonically positive. This happens because mean reversion reduces the value of capacity adjustment options. More details are provided in the Internet Appendix.

## II. Empirical Analysis

In this section, we empirically examine the shape of the expected return-capacity overhang relation and its implications for stock anomalies. To this end, we first describe how we use a stochastic frontier model to estimate stock-level capacity overhang. We next use capacity overhang estimates obtained from the model in portfolio sorts and FM regressions to identify the shape of the expected return-capacity overhang relation. We expect a positive or U-shaped relation when investments are costly to reverse and a negative relation when investments are cheap to reverse. Finally, we use the capacity overhang estimates in horse races with value, momentum, investment, and profitability anomaly variables to study whether real options models help explain the stock pricing ability of the anomaly variables.

An alternative approach to investigating whether real options models help explain stock anomalies would be to calibrate the models to data (see Carlson, Fisher, and Giammarino (2004), Cooper (2006), and Hackbarth and Johnson (2015)). While calibration exercises are informative, they have two drawbacks. First, while it is hard to justify any a priori choice of values for the nonintuitive and unobservable capacity adjustment prices $k$ and $d$ in a calibration exercise, it is the values of the capacity adjustment prices that largely determine the shape of the expected return-capacity overhang relation. Estimating $k$ and $d$ by calibrating the real options model to stock data does not completely solve that problem since the estimated values will likely simply reflect the dominant anomalies in the data. A second drawback is that calibration exercises assume that firms are homogeneous in model parameters, such as demand volatility or production costs. As a result, we believe that our more standard asset pricing tests are able to complement calibration exercises.

## A. Measuring Capacity Overhang

### A.1. The Stochastic Frontier Model

We first review our stochastic frontier model approach to estimating stock-level capacity overhang.[9] Stochastic frontier models are suitable to estimate stock-level capacity overhang since the real options model in Section I suggests that capacity overhang is truncated from below at zero. To see how stochastic frontier models work, decompose firm $i$'s installed capacity at time $t$, $\bar{K}_{i,t}$, into optimal capacity, $K_{i,t}^*$, and a capacity overhang term $\xi_{i,t}$,

$$\bar{K}_{i,t} = K_{i,t}^* \xi_{i,t}, \tag{10}$$

where $\xi_{i,t} \in [1, +\infty)$. Taking the natural log of both sides, we obtain

$$\ln(\bar{K}_{i,t}) = \ln\left(K_{i,t}^*\right) + \ln(\xi_{i,t}) = \ln\left(K_{i,t}^*\right) + u_{i,t}, \tag{11}$$

where $u_{i,t} \equiv \ln(\xi_{i,t}) \geq 0$. We next assume that the natural log of optimal capacity, $\ln(K_{i,t}^*)$, is a linear function of optimal capacity determinants, possibly including fixed effects (see Greene (2005)), and a normally distributed white-noise error term $v_{i,t}$. We can then write

$$\ln(\bar{K}_{i,t}) = \alpha_k + \boldsymbol{\beta}'\mathbf{X}_{i,t} + v_{i,t} + u_{i,t} = \alpha_k + \boldsymbol{\beta}'\mathbf{X}_{i,t} + \epsilon_{i,t}, \tag{12}$$

where $\mathbf{X}_{i,t}$ is a vector of optimal capacity determinants, $\alpha_k$ are fixed effects, $\boldsymbol{\beta}$ is a vector of parameters, $v_{i,t} \sim N(0, \sigma_v^2)$, with $\sigma_v^2$ being a parameter, and $\epsilon_{i,t} \equiv v_{i,t} + u_{i,t}$ is the combined error term. The model is completed by assuming a distribution for the log capacity overhang term $u_{i,t}$, with prior studies offering a menu of choices. We choose the normal distribution truncated from below

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[9] Stochastic frontier models were independently developed by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977). An excellent textbook treatment is Kumbhakar and Lovell (2000).

at zero since it is the only distribution that allows us to model the conditional mean of the $u_{i,t}$ term as a function of determinants, imposing further discipline. Thus, $u_{i,t} \sim N^+(\boldsymbol{\gamma}'\boldsymbol{Z}_{i,t}, \sigma_u^2)$, where $\boldsymbol{Z}_{i,t}$ is a vector of capacity overhang determinants, $\boldsymbol{\gamma}$ is a vector of parameters, and $\sigma_u^2$ is a parameter. Crucially, since $\mathbf{X}_{i,t}$ and $\boldsymbol{Z}_{i,t}$ contribute differently to an observation's likelihood, it is important to distinguish between the variables contained in $\mathbf{X}_{i,t}$ and $\boldsymbol{Z}_{i,t}$.

We use maximum likelihood techniques to recursively estimate the stochastic frontier model on monthly data. The first recursive window is July 1963 to December 1971. We expand the recursive windows on an annual basis, ending each in December, so that, for example, the second window ends in December 1972. The final window ends in December 2013.

While we are ultimately interested in the log capacity overhang term $u_{i,t}$, the estimation output provides us with an estimate of the combined error term $\epsilon_{i,t}$ but not $u_{i,t}$. Following other studies in the stochastic frontier literature, we thus calculate the conditional expectation of the $u_{i,t}$ term. To do so, we define $\mu_{i,t}^* = \frac{\epsilon_{i,t}\sigma_u^2 + \boldsymbol{\gamma}'\boldsymbol{Z}_{i,t}\sigma_v^2}{\sigma_u^2 + \sigma_v^2}$ and $\sigma_{i,t}^* = \sigma_u\sigma_v/\sqrt{\sigma_u^2 + \sigma_v^2}$. We then calculate the conditional expectation of the log capacity overhang term, $\hat{u}_{i,t}$, using

$$\hat{u}_{i,t} = \mathrm{E}[u_{i,t}|\epsilon_{i,t}, \boldsymbol{Z}_{i,t}] = \mu_{i,t}^* + \sigma_{i,t}^*\left(\frac{n\left(-\mu_{i,t}^*/\sigma_{i,t}^*\right)}{N\left(\mu_{i,t}^*/\sigma_{i,t}^*\right)}\right), \tag{13}$$

where $n(.)$ and $N(.)$ are the standard normal density and cumulative standard normal density, respectively. In calculating $\hat{u}_{i,t}$, we always combine $\mathbf{X}_{i,t}$ and $\boldsymbol{Z}_{i,t}$ with model parameters estimated using the recursive estimation window ending in December of the prior calendar year, which ensures that $\hat{u}_{i,t}$ could have been calculated by real-time investors in month $t$.

### A.2. Model Variables and Data

We next describe the variables used in the stochastic frontier model, with more details provided in Table CI in Appendix C. In our main specification, we use the sum of a firm's gross PPE and intangible assets to measure installed capacity. We include intangible assets because in the real options model, the firm produces *and sells* output, and many intangibles facilitate the selling process.[10] However, for consistency with prior studies, in two alternative specifications, we use gross PPE on its own and total assets to measure installed capacity. Total assets is likely to be a noisy proxy for installed capacity because it includes financial assets not used in the production and selling process. We nevertheless use total assets, first for falsification purposes and second because it is often used in investment-based asset pricing studies (e.g., Cooper, Gulen, and Schill (2008)).

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[10] Examples include customer-related intangibles, such as customer lists, order backlogs, and customer relations; contract-related intangibles, such as franchises, licensing agreements, service contracts, and use rights; and technology-related intangibles, such as patents, software, and trade secrets.

We choose the optimal capacity determinants in $X_{i,t}$ based on equation (7), the implicit function identifying a firm's optimal capacity in the real options model. The equation suggests that optimal capacity depends on demand, the elasticity of demand, production costs, capacity purchase and resale prices, systematic risk, demand volatility, and the risk-free rate of return. We include the natural logs of sales, costs of goods sold (COGS), and selling, general, and administrative costs (SGA) to capture demand and production cost effects; the conditional market beta estimate proposed by Lewellen and Nagel (2006) to proxy for systematic risk; historical stock volatility calculated from daily data over the prior 12 months to proxy for demand volatility; and the three-month Treasury bill rate to proxy for the risk-free rate of return. We capture unobservable variables such as the elasticity of demand and the capacity adjustment prices using industry fixed effects. We estimate industry fixed effects based on Campbell's (1996) 12-industry classification scheme.

We choose the capacity overhang determinants in $Z_{i,t}$ based on the real options model's implication that a firm with positive capacity overhang must have enjoyed higher demand for its output at some point in the past than now. To capture the effects of falling demand, we include the recent decline in sales, defined as the percentage decline in sales over the prior 12 months, and the more distant decline in sales, defined as the percentage decline from the 12-month lagged maximum of a firm's sales over its entire history to 12-month lagged sales. We set negative declines to zero. We separately study recent and more distant sales declines to see how persistent the effects of sales declines are. We also include a dummy variable indicating whether a firm realized a loss over the prior 12 months, since optimal capacity firms are always profitable in real options models.[11] We note that the asymmetries in the capacity overhang determinants give us identification that is different from other studies.[12]

Market data are from CRSP, while accounting data are from Compustat. Since capacity overhang is unlikely to have a long-lasting effect on stock returns,[13] we require a timely estimate of capacity overhang. To this end, we

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[11] In a robustness test, we also include interactions between each capacity overhang determinant and the investment reversibility proxy introduced below, which allows the effects of the capacity overhang determinants to vary with investment reversibility costs. However, since these interactions are never important, we do not use them in the models estimated in the paper. The insignificance of the interactions is consistent with our later empirical finding that the effect of investment reversibility does not vary strongly across stocks.

[12] The evidence in Bloom (2009) supports the asymmetries in the capacity overhang determinants. In particular, Bloom (2009) notes that "[profitable] firms are located near their hiring and investment thresholds, above which they hire/invest and below which they have a zone of inaction[, so that] small positive shocks generate a hiring and investment response while small negative shocks generate no response" (p. 625).

[13] When investments are reversible, neither the high expected returns of low-capacity overhang stocks nor the low expected returns of high-capacity overhang stocks are persistent. Consider a low-capacity overhang firm. Upon goods news, this firm invests, converting high-risk growth options into low-risk production options; upon bad news, the firm's options portfolio rebalances toward lower risk production options. Thus, any news lowers this firm's expected return. Consider a high-capacity overhang firm. Upon good news, the firm's options portfolio rebalances toward

use quarterly data to calculate the accounting variables used in our estimations, relying on annual data only when quarterly data are unavailable. In line with Campbell, Hilscher, and Szilagyi (2008), we assume that quarterly accounting data are reported with a two-month lag, while annual accounting data are reported with a three-month lag.[14] To ensure that numbers calculated from annual and quarterly data are comparable and not affected by seasonal variations, flow variables calculated from quarterly data are four-quarter trailing sums. Since the vast majority of firms start reporting quarterly data as of 1972, the use of annual accounting data allows us to obtain a first set of recursively estimated stochastic frontier model parameters in December 1971. For the same reason, the capacity overhang estimate used in our asset pricing tests starting in January 1972 typically relies on annual accounting data through the stochastic frontier model parameter estimates, not through the model's variables. We study common stocks traded on the NYSE, Amex, or NASDAQ, excluding financial stocks (SIC Code: 6000-6999) and utilities (4900-4949). All variables except for the stock return are winsorized at the 1$^{st}$ and 99$^{th}$ percentiles, calculated each month; level variables are deflated using the Producer Price Index (PPI).

### A.3.  Model Estimates

We next discuss the estimation results from the stochastic frontier model. While we use a recursively fitted capacity overhang estimate in our asset pricing tests, Table I shows the results obtained over the full sample period. Columns (1) and (2) use PPE plus intangibles to measure installed capacity, columns (3) and (4) use PPE, and columns (5) and (6) use total assets. In each case, we estimate one model specification using all optimal capacity determinants and one using all optimal capacity determinants except stock volatility. We drop stock volatility from some model specifications since Ang et al. (2006, 2009) show that stock volatility negatively prices stocks, raising the concern that it could drive the stock return-capacity overhang relation found in our empirical work. Panels A, B, and C report the coefficient estimates of the optimal capacity determinants, the capacity overhang determinants, and $\sigma_v$ and $\sigma_u$, respectively, with $t$-statistics presented in square brackets.

Panel A suggests that sales is the most important determinant of optimal capacity, with its coefficient being positive and highly significant in all columns. COGS and SGA costs also have significant positive coefficients, but the magnitudes of the coefficients are generally lower than those for sales. The more positive effect of sales is unsurprising since sales reflect the price at which output is sold ($P$) and output volume ($Q$), with both variables expected to be positively related to optimal capacity. In contrast, the cost variables reflect

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higher risk production options; upon bad news, the firm divests, converting low-risk production options into high-risk growth options. Thus, any news raises this firm's expected return.

[14] Lagging the quarterly and annual accounting data by one or two more months does not change any of our empirical conclusions.

**Table I**
## Stochastic Frontier Model Estimates

The table presents the results from estimating the stochastic frontier model in equation (12) over the full sample period. We proxy for productive capacity using gross property, plant, and equipment (PPE) plus intangibles in columns (1) and (2), PPE in columns (3) and (4), and total assets in columns (5) and (6). The determinants of optimal capacity consistently include *Sales*, *COGS*, *SGA*, *MarketBeta*, and *RiskfreeRate*; *StockVolatility* is included only in a subset of the models. The determinants of capacity overhang include *RecentSalesDecline*, *DistantSalesDecline*, and *LossDummy*. Each model also contains Campbell (1996) industry fixed effects. All level variables are deflated to constant U.S. dollars using the Purchaser Price Index (PPI). See Table CI for variable definitions. Panels A and B give the estimates of the optimal capacity and capacity overhang determinant parameters, while Panel C gives the residual volatilities of optimal capacity and capacity overhang. *t*-statistics are shown in square brackets. The table also provides the number of observations and the log-likelihood.

| | Productive Capacity Proxy | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | PPE + Intangibles | | PPE | | Total Assets | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Panel A: Optimal Capacity Determinants | | | | | | |
| *Sales* | 0.72 | 0.74 | 0.63 | 0.65 | 0.79 | 0.81 |
| | [401.8] | [411.5] | [367.3] | [375.8] | [621.0] | [633.1] |
| *COGS* | 0.23 | 0.23 | 0.30 | 0.31 | 0.09 | 0.09 |
| | [142.0] | [144.5] | [194.5] | [198.2] | [77.9] | [77.4] |
| *SGA* | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| | [50.2] | [48.3] | [19.7] | [18.0] | [15.1] | [11.9] |
| *StockVolatility* | −0.22 | | −0.23 | | −0.18 | |
| | [−129.0] | | [−143.2] | | [−186.9] | |
| *MarketBeta* | 0.06 | 0.04 | 0.07 | 0.05 | 0.08 | 0.06 |
| | [53.5] | [32.3] | [67.0] | [44.0] | [134.5] | [103.0] |
| *RiskfreeRate* | −0.53 | −0.46 | 0.09 | 0.16 | −0.47 | −0.41 |
| | [−152.3] | [−134.1] | [27.4] | [48.5] | [−231.3] | [−199.3] |
| Panel B: Capacity Overhang Determinants | | | | | | |
| *RecentSalesDecline* | 0.72 | 0.72 | 0.63 | 0.64 | 1.29 | 1.30 |
| | [85.1] | [83.4] | [73.2] | [70.9] | [215.3] | [212.4] |
| *DistantSalesDecline* | 0.09 | 0.13 | −0.14 | −0.11 | 0.38 | 0.42 |
| | [12.7] | [17.3] | [−17.2] | [−13.5] | [77.6] | [83.2] |
| *LossDummy* | 0.56 | 0.46 | 0.44 | 0.31 | 0.49 | 0.41 |
| | [152.2] | [120.7] | [115.2] | [77.9] | [194.8] | [157.6] |
| Panel C: Residual Volatilities | | | | | | |
| *OptimalCapacity* ($\sigma_v^2$) | 0.58 | 0.58 | 0.53 | 0.51 | 0.84 | 0.85 |
| | [168.8] | [159.1] | [129.4] | [112.8] | [886.3] | [882.9] |
| *CapacityOverhang* ($\sigma_u^2$) | 0.97 | 0.97 | 1.00 | 1.01 | 0.37 | 0.38 |
| | [940.8] | [935.9] | [964.1] | [949.6] | [625.5] | [634.0] |
| Industry Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations (in 1,000s) | 1,550 | 1,550 | 1,718 | 1,718 | 1,719 | 1,719 |
| Log Likelihood (in 1,000s) | −2,262 | −2,271 | −2,532 | −2,543 | −1,696 | −1,714 |
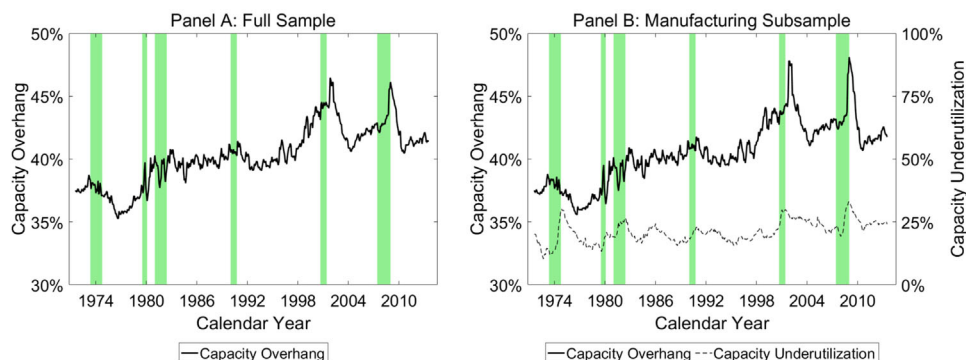
**Figure 4. Mean capacity overhang-to-installed capacity ratio over the sample period.** The figure plots the mean of the capacity overhang-to-installed capacity ratio, calculated as $1 - 1/\exp(\hat{u}_{i,t})$, over the 1972 to 2013 sample period. Panel A calculates the mean over the full sample. Panel B calculates the mean over only those stocks operating in industries for which we can also calculate and plot a survey-based estimate of mean capacity underutilization. The green bars identify NBER-defined recession periods. (Color figure can be viewed at wileyonlinelibrary.com)

average unit costs (determined by $c_1$ and $c_2$) and output volume ($Q$), with average unit costs expected to be negatively, but output volume expected to be positively, related to optimal capacity. In accordance with real options theory, stock volatility is significantly negatively related to optimal capacity. While the market beta and the risk-free rate of return also produce statistically significant coefficients in all model specifications, their effects on optimal capacity are economically negligible.

Panel B shows that the capacity overhang determinants also produce significant coefficients with the expected signs in the vast majority of cases. For example, with the exception of the sales decline over the more distant past in columns (3) and (4), the sales declines over both the recent past and the more distant past increase capacity overhang. Crucially, however, recent sales declines have a much stronger effect than more distant sales declines, suggesting that firms divest capacity overhang over time and that investments are not completely irreversible. Finally, the loss dummy variable also loads positively and significantly on capacity overhang.

Panel C shows that the volatility of the log capacity overhang term $u_{i,t}$ is about twice the volatility of the optimal capacity error $v_{i,t}$. This is noteworthy because, if the volatility of $v_{i,t}$ strongly dominated the volatility of $u_{i,t}$, the stochastic frontier model estimates would converge to their OLS counterparts in the asymptotic limit (see Kumbhakar and Lovell (2000)). In this case, we would no longer need to distinguish between the variables in $\boldsymbol{X}_{i,t}$ and $\boldsymbol{Z}_{i,t}$.

Figure 4 plots the mean capacity overhang-to-installed capacity ratio, $(\bar{K}_{i,t} - K^*_{i,t})/\bar{K}_{i,t} = 1 - 1/\exp(\hat{u}_{i,t})$, over our sample period, using the capacity overhang estimate based on the sum of PPE and intangibles and including stock volatility. Panel A plots the mean over the full sample of stocks. Panel B plots the mean over only those stocks in industries for which we also have
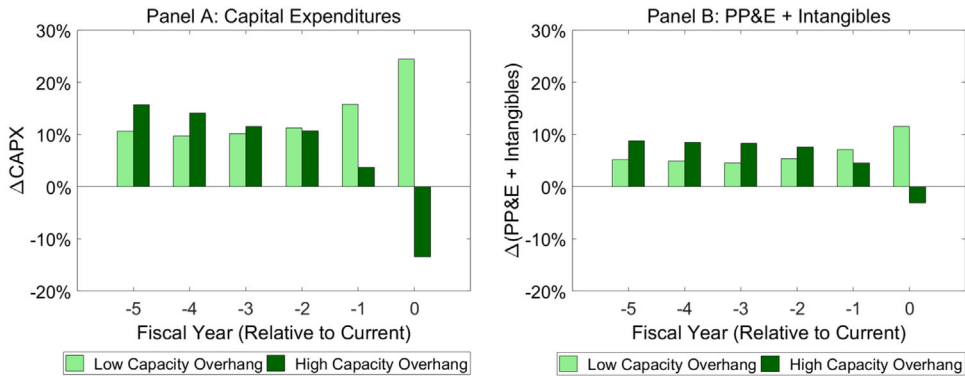
**Figure 5. Investment behavior of high- and low-capacity overhang stocks.** The figure plots the annual growth in CAPX (Panel A) and PPE plus intangibles (Panel B) of high- and low-capacity overhang stocks over the prior six fiscal years. We define high- (low-) capacity overhang stocks as stocks with a capacity overhang value above the ninth decile (below the first decile) at the end of December of year 0. (Color figure can be viewed at wileyonlinelibrary.com)

a Bureau of Economic Analysis (BEA) survey estimate of capacity utilization, which allows us to add mean industry-level capacity "underutilization" (i.e., one minus capacity utilization) to the panel. The green bars identify NBER-defined recession periods. The figure indicates that the mean capacity overhang-to-installed capacity ratio lies between 35% and 49%. In line with intuition, the mean ratio rises sharply in recessions. In line with Cooper, Wu, and Gerard's (2005) argument that capacity underutilization proxies for capacity overhang, mean capacity overhang shares a correlation of about 0.60 with mean capacity underutilization.

### A.4. Capacity Overhang Validation Tests

We use two tests to validate the capacity overhang estimate based on the sum of PPE and intangibles and including stock volatility. We first compare the past investment behavior of high- and low-capacity overhang stocks. We expect high- (low-) capacity overhang stocks to have decreased (increased) their investments over the recent past. Figure 5 plots the mean annual growth rates in capital expenditures (CAPX; Panel A) and capacity (PPE plus intangibles; Panel B) for the two groups of stocks over the prior six years. High- (low-) capacity overhang stocks are top (bottom) capacity overhang decile stocks at the end of December of year $t$. The growth rate in year $t - j$ is the net percentage change from the fiscal year ending in year $t - j - 1$ to the fiscal year ending in year $t - j$, where $j \in \{0, 1, 2, 3, 4, 5\}$. More details about the variables are provided in Table CI in Appendix C. We calculate means separately by year $t$, lag $j$, and capacity overhang decile 1 or 10 and then average over years.

Figure 5 reveals that while high-capacity overhang stocks have significantly reduced their investment rates over the recent past, low-capacity overhang
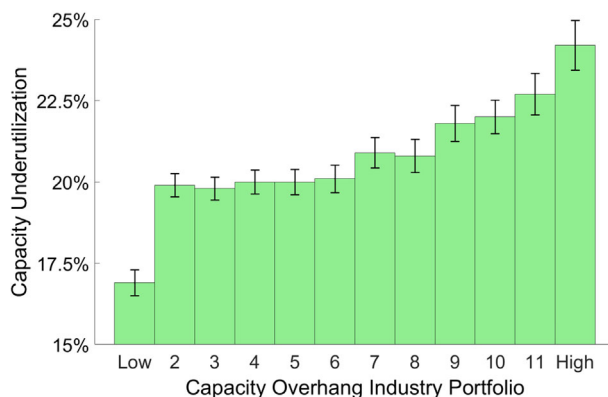
**Figure 6. Capacity utilization of capacity overhang-sorted industry portfolios.** The figure plots the average capacity underutilization (one minus capacity utilization) of capacity overhang-sorted industry portfolios, where the average is calculated as the time-series average of the cross-sectional average taken over all industries in a portfolio. The black lines are 95% confidence intervals. The industry-level capacity overhang estimate is the value-weighted average of the single-stock estimate over all stocks in an industry in a month. Industries are sorted into portfolios according to the contemporaneous industry-level capacity overhang estimate, with portfolios 1 and 12 each containing one industry and all other portfolios containing two industries. (Color figure can be viewed at wileyonlinelibrary.com)

stocks have significantly raised their investment rates, especially over the two most recent years. For example, Panel A shows that the CAPX growth of high-capacity overhang stocks has decreased by an average of close to 30 percentage points from year $t-5$ to year $t$, while the CAPX growth of low-capacity over-hang stocks has increased by an average of about 14 points. Interestingly, the high-capacity overhang stocks have higher average CAPX and capital growth than the low-capacity overhang stocks in year $t-5$, suggesting that they are similar to Chan and Chen's (1991) "fallen angels." Also interestingly, the high-capacity overhang stocks have negative average capacity growth in year $t$, again suggesting that investment decisions cannot be completely irreversible.

In our second validation test, we investigate the ability of estimated capacity overhang to explain cross-sectional variation in industry-level capacity under-utilization obtained from BEA survey data, as also used in Figure 4. At the end of each month in our sample period, we calculate the value-weighted av-erage of the capacity overhang estimate for each of the 22 industries surveyed by the BEA. We sort the 22 industries into 12 portfolios according to the con-temporaneous industry-level capacity overhang estimate, with portfolios 1 and 12 containing one industry and the other portfolios containing two industries. Portfolio 1 contains the lowest capacity overhang industry, while portfolio 12 contains the highest. Figure 6 suggests that mean capacity underutilization in-creases almost monotonically over the portfolios. While portfolio 1 has a mean underutilization of about 17%, portfolio 12 has a mean underutilization of about 24%. The difference is a highly significant 7% (*t*-statistic: 5.24).

## B. The Pricing of Capacity Overhang

### B.1. Univariate Capacity Overhang Portfolios

We first use univariate portfolio sorts to study the pricing of capacity overhang. At the end of each month $t-1$ in our sample period, we sort stocks into portfolios according to the $5^{th}$, $10^{th}$, $20^{th}$, $40^{th}$, $60^{th}$, $80^{th}$, $90^{th}$, and $95^{th}$ percentiles of recursively estimated capacity overhang (see equation (13)). Similar to Campbell, Hilscher, and Szilagyi (2008), our portfolio sorts pay greater attention to the tails of the capacity overhang distribution to produce a more even increase in capacity overhang over the portfolios. The first portfolio ("00-05") contains stocks with low-capacity overhang values, while the last portfolio ("95-100") contains stocks with high values. Unless otherwise stated, in all portfolio sorts, we use the capacity overhang estimate derived from the sum of PPE and intangibles and including stock volatility, we calculate portfolio break points exclusively from NYSE stocks, and we value-weight portfolios and hold them over month $t$. Finally, we construct a capacity overhang spread portfolio long on the highest and short on the lowest capacity overhang portfolio ("LS9505").

We adjust for risk by regressing a portfolio's "excess return" (i.e., the portfolio's return minus the risk-free rate of return) on the benchmark factors of the CAPM, the Hou, Xue, and Zhang (2015) $Q$-theory model, and the Fama and French (2015) five-factor model. We then report the intercepts ("alphas").[15] We use the Gibbons, Ross, and Shanken (GRS; 1989) $F$-test to determine whether the models correctly price the portfolios. Unless otherwise stated, our asset pricing tests are run over monthly data from 1972 to 2013. Stock data are from CRSP. More details about our asset pricing variables are provided in Table CI in Appendix C.

Table II presents the mean excess returns and alphas (both annualized and in percent) and selected characteristics of the capacity overhang portfolios. The characteristics are the average number of stocks, the average capacity overhang-to-installed capacity ratio, and the average log market size, where the last two averages are time-series averages of the cross-sectional averages taken over the stocks in a portfolio. We report $t$-statistics of the mean excess return and alphas of the spread portfolio, calculated using Newey and West's (1987) formula with a lag length of 12, in square brackets. The table shows that mean excess returns decline almost monotonically over the capacity overhang portfolios, from 10.0% per annum for the lowest capacity overhang portfolio to –2.5% for the highest portfolio. The spread is a highly significant –12.5% ($t$-statistic: –4.20). Interestingly, about two-thirds of the spread come from the highest capacity overhang portfolio. The portfolios are well diversified, with even the extreme portfolios containing more than 200 stocks on average. Owing

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[15] The CAPM's only factor is the excess market return. Both the $Q$-theory model and the five-factor model add the returns of spread portfolios on size (small-minus-large), investment (conservative-minus-aggressive), and profitability (profitable-minus-unprofitable). The five-factor model also adds the return on a book-to-market spread portfolio (high-minus-low book-to-market). See Fama and French (2015) and Hou, Xue, and Zhang (2015) for details. We thank Kenneth French and Lu Zhang for providing their benchmark factor data.

<div align="center">

Table II

**Portfolios Sorted by Capacity Overhang**
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The table presents the mean excess returns and alphas of portfolios univariately sorted on *CapacityOverhang*. We calculate *CapacityOverhang* using gross PPE plus intangibles as the proxy for productive capacity and including *StockVolatility* among the determinants of optimal capacity. More details about *CapacityOverhang* are in Table CI. At the end of each month $t-1$, we sort all stocks into portfolios using the 5th, 10th, 20th, 40th, 60th, 80th, 90th, and 95th percentiles of the *Capacity Overhang* distribution of NYSE stocks in that month as break points. We value-weight the portfolios and hold them over month $t$. We form a spread portfolio long the highest and short the lowest portfolio ("LS95-05"). The table reports the mean number of stocks, the mean *CapacityOverhang* value, and the mean log market size per portfolio. It also reports the mean excess return and the CAPM, *Q*-theory model, and five-factor (FF5) model alphas, all annualized and in percent. *t*-statistics for the mean excess return and alphas of the spread portfolio, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets. The table also reports the *F*-statistic from the GRS test of the joint significance of the factor model alphas, with the associated *p*-value shown in parentheses.

| Portfolio | Mean Stock Number | Capacity Overhang | Log Market Size | Mean Excess Return | CAPM Alpha | Q Alpha | FF5 Alpha |
|---|---|---|---|---|---|---|---|
| 00-05 | 242 | 0.206 | 11.09 | 9.99 | 2.74 | 6.46 | 7.82 |
| 05-10 | 178 | 0.248 | 11.43 | 7.70 | 1.20 | 4.80 | 5.14 |
| 10-20 | 290 | 0.271 | 11.66 | 7.63 | 0.88 | 1.45 | 1.69 |
| 20-40 | 463 | 0.300 | 11.92 | 7.56 | 1.39 | 0.06 | 0.28 |
| 40-60 | 422 | 0.331 | 12.04 | 6.41 | 0.11 | −0.16 | −0.67 |
| 60-80 | 453 | 0.370 | 11.79 | 6.84 | 0.26 | 0.41 | −0.75 |
| 80-90 | 313 | 0.430 | 11.01 | 6.25 | −0.82 | 0.12 | −2.25 |
| 90-95 | 181 | 0.496 | 10.71 | 6.12 | −1.91 | −0.19 | −3.41 |
| 95-100 | 275 | 0.612 | 10.31 | −2.47 | −11.52 | −2.76 | −8.06 |
| LS95-05 | | | | −12.46 | −14.26 | −9.23 | −15.87 |
| *t*-statistic | | | | [−4.20] | [−5.11] | [−4.13] | [−6.58] |
| GRS | | | | | 3.48 | 2.50 | 4.53 |
| *p*-value | | | | | (0.00) | (0.01) | (0.00) |

to our choice of portfolio break points, average capacity overhang rises close to evenly over the portfolios. Finally, both high- and low-capacity overhang stocks are relatively small stocks.

The alphas of the spread portfolio in Table II suggest that the CAPM, the *Q*-theory model, and the five-factor model cannot explain the mean spread return over the capacity overhang portfolios. While the spread portfolio alphas of the CAPM and the five-factor model are even more negative and significant than the spread portfolio mean excess return, the alpha of the *Q*-theory model is about 25% less negative, but still highly significant (*t*-statistic: –4.13). To better understand the alphas, Figure 7 shows the betas of the capacity overhang portfolios on the benchmark factors of the three models. Panel A suggests that the CAPM market beta increases over the capacity overhang portfolios, and thus the model is unable to explain why high-capacity overhang stocks underperform low-capacity overhang stocks. Conversely, Panels B and C suggest that the profitability betas of the *Q*-theory model and the five-factor model
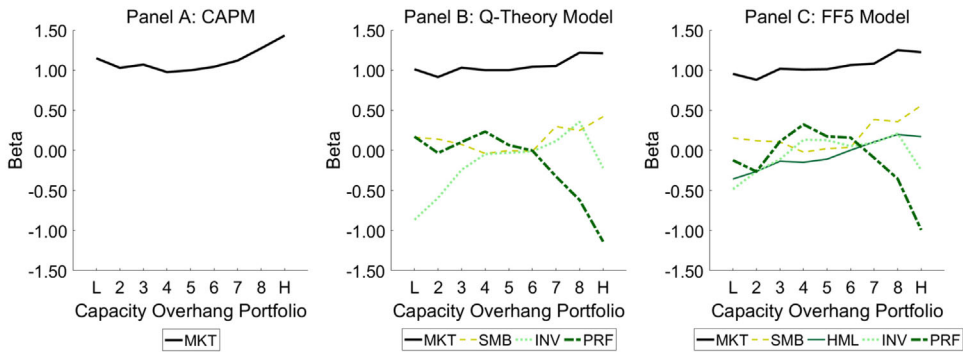
**Figure 7. Betas of the capacity overhang portfolios.** The figure plots the CAPM (Panel A), *Q*-theory model (Panel B), and five-factor model (Panel C) beta exposures of the capacity overhang portfolios. "MKT" is the market beta, "SMB" the small-minus-big size beta, "HML" the high-minus-low book-to-market beta, "INV" the low-minus-high investment beta, and "PRF" the profitable-minus-unprofitable beta. (Color figure can be viewed at wileyonlinelibrary.com)

fall sharply over the capacity overhang portfolios, from 0.15 to –1.12 for the *Q*-theory model and from –0.12 to –0.97 for the five-factor model. While the spreads in the profitability betas help the two models explain the mean spread portfolio return (with the *Q*-theory model's profitability factor explaining a greater fraction of the mean spread portfolio return, as its premium is about twice the premium of the five-factor model's profitability factor), the spreads in the betas of the models' other benchmark factors all work against explaining the mean spread portfolio return. Most strikingly, the beta of the *Q*-theory model's investment factor increases over the capacity overhang portfolios from –0.89 to –0.23.

Accordingly, the GRS tests in Table II suggest that the CAPM, the *Q*-theory model, and the five-factor model all misprice the capacity overhang portfolios. While the CAPM (*Q*-theory model) struggles to price high- (low-) capacity overhang stocks, the five-factor model struggles to price both high- and low-capacity overhang stocks. Adjusting for the benchmark factors of the *Q*-theory or five-factor model, mean excess returns decline more evenly over the portfolios, with a significant fraction of the spread coming from low-capacity overhang stocks.

## B.2. Double-Sorted Capacity Overhang and Market Size Portfolios

To address Fama and French's (2008) concern that many asset pricing results are driven by microcap stocks, we next study portfolios independently double-sorted on capacity overhang and market size. At the end of each month $t-1$ in our sample period, we first sort stocks into three portfolios according to the first decile and the first quartile of market size. We label the stocks in the first, middle, and last portfolio micro stocks, small stocks, and large stocks, respectively. We independently sort stocks into portfolios according to the 5th, 10th, 20th, 40th, 60th, 80th, 90th, and 95th percentiles of the capacity

overhang estimate in month $t - 1$. The intersection of the market size and capacity overhang break points produces 27 double-sorted portfolios. Within each market size portfolio, we finally construct a spread portfolio long on the highest capacity overhang portfolio and short on the lowest ("LS9505").

Table III presents the same statistics as Table II, but here they are presented separately for micro stocks (Panel A), small stocks (Panel B), and large stocks (Panel C). The table shows that each market size portfolio accounts on average for about one-third of the cross section. The average market size of micro stocks, however, is only about $24 million, relative to about $163 million for small stocks and $3.7 trillion for large stocks. More importantly, the table shows that both mean excess returns and alphas decline over the capacity overhang portfolios within each market size portfolio. Although the spreads over the portfolios are generally more negative and more significant within the micro-stock and small-stock portfolios, even large stocks produce negative and significant spreads, with, for example, the mean spread portfolio return being –11.8% per annum for those stocks (*t*-statistic: –3.68). Thus, while we can confirm Fama and French's (2008) conjecture that asset pricing results are often weaker among larger stocks, the evidence in this subsection demonstrates that the pricing of the capacity overhang estimate does not come exclusively from micro or small stocks.

### B.3. Double-Sorted Capacity Overhang and Reversibility Portfolios

We next study portfolios independently double-sorted on capacity overhang and an investment reversibility proxy. We do so to test the real options model prediction that costlier-to-reverse investments increase expected returns, especially for high-capacity overhang stocks, perhaps generating a U-shaped stock return-capacity overhang relation among stocks with costlier-to-reverse investments (see Section I.C.1). To proxy for investment reversibility, we rely on Cooper, Wu, and Gerard's (2005) insight that higher investment reversibility implies that a firm starts to divest at a lower capacity overhang level, reducing the maximum capacity overhang level the firm can build up. Thus, similar to these authors, we calculate the inverse of the time-series volatility of industry capacity overhang, where industry capacity overhang is the median of the capacity overhang estimate for each two-digit SIC industry and volatility is calculated using the full sample period. We next assign the resulting estimates to all firms operating in each industry. A higher proxy value indicates that a firm operates in an industry with less extreme capacity overhang values, suggesting higher investment reversibility.[16]

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[16] Cooper, Wu, and Gerard (2005) actually use the time-series volatility of industry-level capacity utilization rates from BEA surveys, but the intuition behind their proxy and ours is identical. An advantage of using our proxy is that it can be calculated for firms operating in industries not included in the BEA surveys, which make up about half of our sample. Nevertheless, using Cooper, Wu, and Gerard's (2005) proxy in our tests produces similar albeit slightly noisier results relative to those in our paper. Using Schlingemann, Stulz, and Walking's (2002), Sibilkov's (2009), and

Table III

## Portfolios Sorted by Capacity Overhang and Market Size

The table presents the mean excess return and alpha of portfolios independently bivariately sorted on *CapacityOverhang* and *MarketSize*. We calculate *CapacityOverhang* using gross PPE plus intangibles as the proxy for productive capacity and including *StockVolatility* among the determinants of optimal capacity. More details about the variables are provided in Table CI. At the end of each month $t - 1$, we sort stocks into capacity overhang portfolios using the $5^{th}$, $10^{th}$, $20^{th}$, $40^{th}$, $60^{th}$, $80^{th}$, $90^{th}$, and $95^{th}$ percentiles of the *CapacityOverhang* distribution of NYSE stocks in that month as break points. We independently sort stocks into size portfolios using the $5^{th}$ and the $25^{th}$ percentiles of the *MarketSize* distribution of NYSE stocks in that month as break points. We label the stocks in the three portfolios micro stocks (Panel A), small stocks (Panel B), and large stocks (Panel C), respectively. The intersection of the two sets of portfolios yields 27 bivariately sorted portfolios. We value-weight the portfolios and hold them over month $t$. Within each size portfolio, we form a spread portfolio long the highest and short the lowest capacity overhang portfolio ("LS95-05"). The table reports the mean number of stocks, the mean *CapacityOverhang* value, and the mean log market size per portfolio. It also reports the mean excess return and the CAPM, *Q*-theory model, and five-factor (FF5) model alphas, all annualized and in percent. *t*-statistics for the mean returns and alphas of the spread portfolios, calculated using Newey and West's (1987) formula with a lag length of 12 months, are shown in square brackets.

| Portfolio | Mean Stock Number | Capacity Overhang | Log Market Size | Mean Excess Return | CAPM Alpha | Q Alpha | FF5 Alpha |
|---|---|---|---|---|---|---|---|
| Panel A: Micro Stocks (Average Number: 1,032; Average Size: $24 million) | | | | | | | |
| 00-05 | 103 | 0.203 | 9.46 | 16.55 | 9.60 | 9.84 | 7.34 |
| 05-10 | 63 | 0.247 | 9.57 | 16.02 | 9.24 | 9.50 | 7.24 |
| 10-20 | 88 | 0.271 | 9.57 | 16.11 | 9.87 | 8.54 | 6.34 |
| 20-40 | 123 | 0.300 | 9.56 | 13.16 | 6.37 | 6.81 | 3.81 |
| 40-60 | 114 | 0.331 | 9.53 | 12.80 | 5.74 | 7.61 | 4.00 |
| 60-80 | 144 | 0.372 | 9.46 | 10.90 | 3.61 | 6.22 | 1.85 |
| 80-90 | 143 | 0.432 | 9.34 | 6.82 | −0.85 | 5.53 | 0.51 |
| 90-95 | 93 | 0.497 | 9.29 | 2.45 | −5.65 | 1.13 | −5.85 |
| 95-100 | 161 | 0.618 | 9.20 | −1.26 | −9.66 | −1.36 | −8.36 |
| LS95-05 | | | | −17.81 | −19.26 | −11.20 | −15.69 |
| *t*-statistic | | | | [−5.35] | [−6.05] | [−3.59] | [−4.94] |
| Panel B: Small Stocks (Average Number: 928; Average Size: $163 million) | | | | | | | |
| 00-05 | 88 | 0.207 | 11.44 | 12.08 | 3.87 | 2.60 | 1.63 |
| 05-10 | 66 | 0.248 | 11.47 | 10.67 | 2.95 | 1.20 | 0.21 |
| 10-20 | 107 | 0.271 | 11.49 | 12.68 | 4.91 | 2.45 | 1.65 |
| 20-40 | 159 | 0.299 | 11.50 | 11.46 | 3.99 | 1.68 | 0.50 |
| 40-60 | 131 | 0.331 | 11.49 | 11.21 | 3.31 | 2.29 | 0.85 |
| 60-80 | 139 | 0.370 | 11.47 | 9.45 | 1.47 | 1.57 | −0.69 |
| 80-90 | 98 | 0.430 | 11.42 | 8.78 | 0.36 | 3.58 | 0.10 |
| 90-95 | 57 | 0.496 | 11.40 | 2.65 | −6.34 | −2.62 | −6.17 |
| 95-100 | 82 | 0.608 | 11.35 | −4.28 | −13.72 | −6.31 | −11.07 |
| LS95-05 | | | | −16.36 | −17.59 | −8.92 | −12.70 |
| *t*-statistic | | | | [−5.25] | [−5.63] | [−4.08] | [−6.22] |
| Panel C: Large Stocks (Average Number: 857; Average Size: $3.7 trillion) | | | | | | | |
| 00-05 | 50 | 0.210 | 13.65 | 10.05 | 2.80 | 6.95 | 8.45 |
| 05-10 | 49 | 0.248 | 13.74 | 7.63 | 1.20 | 5.06 | 5.43 |

(*Continued*)

**Table III**—*Continued*

| Portfolio | Mean Stock Number | Capacity Overhang | Log Market Size | Mean Excess Return | CAPM Alpha | Q Alpha | FF5 Alpha |
|---|---|---|---|---|---|---|---|
| 10-20 | 95 | 0.271 | 13.69 | 7.30 | 0.61 | 1.39 | 1.64 |
| 20-40 | 181 | 0.300 | 13.86 | 7.48 | 1.36 | 0.13 | 0.35 |
| 40-60 | 177 | 0.331 | 14.03 | 6.31 | 0.04 | −0.20 | −0.69 |
| 60-80 | 170 | 0.369 | 14.00 | 6.70 | 0.16 | 0.37 | −0.76 |
| 80-90 | 72 | 0.427 | 13.66 | 5.99 | −0.98 | −0.19 | −2.42 |
| 90-95 | 31 | 0.495 | 13.57 | 7.44 | −0.49 | 1.06 | −2.08 |
| 95-100 | 32 | 0.588 | 13.35 | −1.71 | −10.80 | −1.47 | −6.88 |
| LS95-05 | | | | −11.75 | −13.60 | −8.43 | −15.32 |
| *t*-statistic | | | | [−3.68] | [−4.46] | [−3.28] | [−5.35] |

Table IV presents the average number of stocks and annualized five-factor model alpha of the double-sorted portfolios.[17] We form the double-sorted portfolios in the table in exactly the same way as those in Table III except that here, we use the median to sort stocks into investment reversibility portfolios, as the investment reversibility proxy takes only a limited number of values, implying that portfolios would often be ill-diversified using a larger set of break points. In line with real options model predictions, the table suggests that higher investment reversibility decreases the five-factor model alpha, especially for high-capacity overhang stocks. To see this, note that the alpha of the lowest capacity overhang portfolio does not vary significantly across the high- and low-investment reversibility portfolios. In contrast, the alpha of the highest capacity overhang portfolio is 8.4% lower per annum in the high than in the low-investment reversibility portfolio (*t*-statistic: –2.64). An implication of these results is that the decline in the alpha over the capacity overhang portfolios is 10.9% lower per annum in the high than in the low-investment reversibility portfolio (*t*-statistic: –2.19). Notwithstanding this observation, the decline in alpha is close to monotonic and significant in *both* the high- and low-investment reversibility portfolio, suggesting that not even low-investment reversibility stocks produce a U-shaped stock return-capacity overhang relation.

## B.4. Portfolio Timing

We next study the stock return-capacity overhang relation in different economic states, arguing that if the true relation were U-shaped, the upward-sloping part of the relation is more likely to manifest in bad states with a higher aggregate capacity overhang (see Figure 4). To do so, Table V repeats the univariate portfolio sorts in Table II, but now separately reports five-factor

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Ortiz-Molina and Phillips's (2014) investment reversibility proxy based on the activity in an industry's real assets market or Kim and Kung's (2016) proxy based on how widely an industry's real assets are used in other industries also produces similar results.

[17] Mean excess returns, CAPM alphas, and *Q*-theory alphas produce similar results both in the tests in this section and in the portfolio timing tests reported in Section II.B.4.

**Table IV**
**Portfolios Sorted by Capacity Overhang and Investment Reversibility**

The table presents the five-factor (FF5) model alphas of portfolios independently bivariately sorted on *CapacityOverhang* and *InvReversibility*. We calculate *CapacityOverhang* using gross PPE plus intangibles as the proxy for productive capacity and including *StockVolatility* among the determinants of optimal capacity. More details about the variables are provided in Table CI. At the end of each month $t-1$, we sort stocks into capacity overhang portfolios using the $5^{th}$, $10^{th}$, $20^{th}$, $40^{th}$, $60^{th}$, $80^{th}$, $90^{th}$, and $95^{th}$ percentiles of the *CapacityOverhang* distribution of NYSE stocks in that month as break points. We independently sort stocks into investment reversibility portfolios using the median of the *InvReversibility* distribution of NYSE stocks in that month as break point. We label the stocks in the first (low value) portfolio low-reversibility stocks and those in the second (high value) portfolio high-reversibility stocks. The intersection of the two sets of portfolios yields 18 bivariately sorted portfolios. We value-weight the portfolios and hold them over month $t$. Within each reversibility (capacity overhang) portfolio, we form a spread portfolio long the highest and short the lowest capacity overhang (reversibility) portfolio ("LS95-05" and "High–Low," respectively). The table reports the mean number of stocks and the five-factor (FF5) model alphas, all annualized and in percent. $t$-statistics for the alphas of the spread portfolios, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets.

| | Investment Reversibility | | | | | |
| | High | | Low | | High-Low | |
| Portfolio | Number Stocks | FF5 Alpha | Number Stocks | FF5 Alpha | FF5 Alpha | *t*-statistic |
|---|---|---|---|---|---|---|
| 00-05 | 123 | 8.95 | 106 | 6.50 | 2.45 | [0.57] |
| 05-10 | 78 | 1.85 | 77 | 5.23 | −3.38 | [−0.98] |
| 10-20 | 134 | 0.19 | 121 | 3.77 | −3.58 | [−1.69] |
| 20-40 | 197 | −0.57 | 207 | 1.34 | −1.90 | [−1.13] |
| 40-60 | 150 | −1.29 | 220 | 0.03 | −1.33 | [−0.70] |
| 60-80 | 146 | −5.19 | 252 | 0.49 | −5.68 | [−2.88] |
| 80-90 | 107 | −6.50 | 176 | −1.18 | −5.32 | [−2.89] |
| 90-95 | 58 | −7.53 | 105 | −2.24 | −5.29 | [−1.73] |
| 95-100 | 63 | −13.35 | 189 | −4.92 | −8.42 | [−2.64] |
| LS95-05 | | −22.30 | | −11.43 | −10.87 | |
| *t*-statistic | | [−6.09] | | [−3.11] | [−2.19] | |

model alphas in good and bad economic states. We use GDP growth over the prior four quarters, industrial production growth over the prior 12 months, and the market return over months $t-36$ to $t-1$ to identify the state, using macroeconomic data from two months after their official release date. We assume that a good (bad) state is observed if the state proxy is above (below) its full-sample median. We obtain the macroeconomic data from the Federal Reserve Bank of St. Louis Economic Database.

Table V suggests that the spread in the five-factor model alpha over the capacity overhang portfolios is more negative in good states than in bad states. For example, the table shows that the spread is –18.5% per annum in high industrial production growth states and –11.2% per annum in low industrial production growth states. Nevertheless, the spread is consistently negative in good and bad states. Thus, in line with prior results, our evidence again

**Table V**

## Portfolios Sorted by Capacity Overhang, by Economic State

The table presents the five-factor (FF5) model alphas of portfolios univariately sorted on *Capacity-Overhang* separately for good and bad economic states. We calculate *CapacityOverhang* using gross PPE plus intangibles as the proxy for productive capacity and including *StockVolatility* among the determinants of optimal capacity. More details about *CapacityOverhang* are provided in Table CI. At the end of each month $t − 1$, we sort all stocks into portfolios using the $5^{th}$, $10^{th}$, $20^{th}$, $40^{th}$, $60^{th}$, $80^{th}$, $90^{th}$, and $95^{th}$ percentiles of the *CapacityOverhang* distribution of NYSE stocks in that month as break points. We value-weight the portfolios and hold them over month $t$. We form a spread portfolio long the highest and short the lowest portfolio ("LS95-05"). The table shows the mean number of stocks and the FF5 model alpha, annualized and in percent, per portfolio. We calculate the FF5 model alphas separately by whether one of three state variables is above its full-sample median. The state variables are industrial production growth over the prior 12 months (*IndProdGrowth*), GDP growth over the prior four quarters (*GDPGrowth*), and the market return over the prior 36 months (*PastMarketReturn*). More details about the state variables are provided in Table CI. *t*-statistics for the FF5 model alphas of the spread portfolio, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets.

| | | FF5 Model Alpha | | | | | |
| | | Industrial Production Growth | | GDP Growth | | Past Mkt. Return | |
| Portfolio | Mean Number Stocks | High | Low | High | Low | High | Low |
|---|---|---|---|---|---|---|---|
| 00-05 | 242 | 8.96 | 5.24 | 8.03 | 7.00 | 6.98 | 7.26 |
| 05-10 | 178 | 6.84 | 2.97 | 8.53 | 2.03 | 5.46 | 3.80 |
| 10-20 | 290 | 2.04 | 1.24 | 0.70 | 2.29 | 1.65 | 2.30 |
| 20-40 | 463 | −0.29 | 0.98 | 0.56 | −0.05 | 0.17 | 0.30 |
| 40-60 | 422 | −1.49 | 0.27 | −0.54 | −1.07 | −0.16 | −1.00 |
| 60-80 | 453 | −2.11 | 1.13 | −2.56 | 0.49 | −0.83 | −0.04 |
| 80-90 | 313 | −3.63 | −0.47 | −3.29 | −1.53 | −4.28 | 0.56 |
| 90-95 | 181 | −6.39 | −0.05 | −5.47 | −0.85 | −3.65 | −1.56 |
| 95-100 | 275 | −9.56 | −5.99 | −14.31 | −2.64 | −8.91 | −5.99 |
| LS95-05 | | −18.52 | −11.23 | −22.34 | −9.63 | −15.88 | −13.25 |
| *t*-statistic | | [−5.52] | [−2.74] | [−6.03] | [−2.54] | [−4.13] | [−3.62] |

suggests that the stock return-capacity overhang relation is negative, and not U-shaped.

### B.5. Fama-MacBeth Regressions

We next run FM regressions of single-stock returns over month $t$ on the month $t − 1$ values of each of the capacity overhang estimates derived from the stochastic frontier models in Table I and controls. The capacity overhang estimates in columns (1) and (2) of Table VI use PPE plus intangibles to proxy for installed capacity, those in columns (3) and (4) use PPE, and those in columns (5) and (6) use total assets. The capacity overhang estimates in columns (1), (3), and (5) include stock volatility as an optimal capacity determinant; those in the other columns do not. To alleviate outlier effects resulting from the capacity overhang estimates being right skewed, we take the natural log of the

**Table VI**
**Fama-MacBeth Regressions on Capacity Overhang**

The table presents the results of Fama-MacBeth (1973) regressions of single-stock returns over month $t$ on *CapacityOverhang* and control variables calculated using data until the end of month $t-1$. The capacity overhang estimate uses gross PPE plus intangibles (columns (1) and (2)), PPE (columns (3) and (4)), or total assets (columns (5) and (6)) as the proxy for productive capacity. Also, the estimate includes (columns (1), (3), and (5)) or excludes (columns (2), (4), and (6)) *StockVolatility* among the determinants of optimal capacity. More details about *CapacityOverhang* and the control variables are provided in Tables CI and CII. Risk premium estimates are per month and in percent; associated $t$-statistics, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets. We exclude a stock from the July of year $t$ to June of year $t+1$ sample period if the stock has a price below \$1 at the start of that period.

| | Productive Capacity Proxy | | | | | |
| | PPE + Intangibles | | PPE | | Total Assets | |
| | Incl. Vol. (1) | Excl. Vol. (2) | Incl. Vol. (3) | Excl. Vol. (4) | Incl. Vol. (5) | Excl. Vol. (6) |
|---|---|---|---|---|---|---|
| *CapacityOverhang* | −0.62 | −0.58 | −0.58 | −0.58 | −0.22 | −0.22 |
| | [−5.40] | [−5.15] | [−4.48] | [−4.41] | [−3.08] | [−3.17] |
| *MarketBeta* | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 |
| | [0.31] | [0.32] | [0.32] | [0.30] | [0.23] | [0.22] |
| *MarketSize* | −0.09 | −0.09 | −0.09 | −0.09 | −0.07 | −0.07 |
| | [−2.07] | [−2.13] | [−2.12] | [−2.06] | [−1.57] | [−1.58] |
| *BookToMarket* | 0.34 | 0.34 | 0.33 | 0.33 | 0.33 | 0.33 |
| | [4.24] | [4.24] | [4.12] | [4.14] | [4.07] | [4.07] |
| *Profit* | 0.04 | 0.04 | 0.06 | 0.07 | 0.02 | 0.02 |
| | [0.27] | [0.30] | [0.44] | [0.53] | [0.11] | [0.15] |
| *ReturnOnEquity* | 1.05 | 1.05 | 1.07 | 1.09 | 1.27 | 1.28 |
| | [4.54] | [4.54] | [4.65] | [4.73] | [5.06] | [5.06] |
| *AssetGrowth* | −0.93 | −0.93 | −0.93 | −0.93 | −0.90 | −0.90 |
| | [−6.57] | [−6.61] | [−6.57] | [−6.61] | [−6.07] | [−6.10] |
| Constant | 1.88 | 1.91 | 1.89 | 1.87 | 2.07 | 2.07 |
| | [2.78] | [2.86] | [2.75] | [2.72] | [3.00] | [3.05] |

estimates. As controls, we use market beta, market size, book-to-market, profitability, ROE, and asset growth. Tables CI and CII in Appendix C provide more details about the variables. To alleviate microstructure biases, the regressions exclude a stock from the start of July of year $t$ to the end of June of year $t+1$ if the stock's price is below \$1 at the end of June of year $t$.

Table VI suggests that all stochastic frontier model capacity overhang estimates are significantly priced in FM regressions. Columns (1) to (4) show that the estimates based on PPE plus intangibles or on PPE on its own have premia of about –60 basis points per month, with highly significant $t$-statistics around –5. Conversely, columns (5) and (6) show that the estimates based on total assets have premia of about –20 basis points, with $t$-statistics of "only" about –3. The less significant pricing of the estimates based on total assets is consistent with the idea that total assets is a less powerful proxy for installed capacity since it includes financial assets. The table also suggests that including stock

volatility among the optimal capacity determinants does not greatly influence the pricing of capacity overhang. The pricing of the controls aligns with the empirical evidence in other studies.

## C. Capacity Overhang and Stock Anomalies

### C.1. Choosing Value, Momentum, Investment, and Profitability Variables

Our evidence in Section II.B suggests that capacity overhang is negatively related to stock returns, in line with real options models able to explain momentum and profitability anomalies, but not with those able to explain value and investment anomalies. To directly test the ability of real options models to explain stock anomalies, we next select anomaly variables whose ability to price stocks can potentially be explained by real options models. Table CII in Appendix C shows that the 20 selected variables include: (i) momentum variables (e.g., the past 6- and 11-month returns; see Panel A); (ii) profitability variables (e.g., sales growth, operating profitability, total profitability, ROE, and the failure probability; see Panel B);[18] (iii) value variables (e.g., the book-to-market ratio and two long-term past returns; see Panel C); and (iv) investment variables (e.g., total accruals, operating accruals, abnormal investment, PPE growth, and asset growth; see Panel D). We also include asset turnover, defined as the ratio of sales to total assets, since it can be interpreted as a less sophisticated proxy for capacity overhang. We calculate the anomaly variables in accordance with established asset pricing literature, as detailed in Table CII in Appendix C.

To test whether capacity overhang helps explain the pricing of an anomaly variable, we run FM regressions of single-stock returns over month $t$ on a capacity overhang estimate, the anomaly variable, and controls in month $t-1$, both separately and jointly using the capacity overhang estimate and the anomaly variable. In our main tests, we use the capacity overhang estimate derived from using PPE plus intangibles as the proxy for installed capacity and including stock volatility among the determinants of optimal capacity. We use the other capacity overhang estimates in tests reported in the Internet Appendix. Since studies identifying the 20 selected anomalies typically control for market beta, market size, and book-to-market, we use the same controls in our tests. See Tables CI and CII in Appendix C for more details about the control variables. We include an observation in the FM regressions related to an anomaly variable only if the capacity overhang estimate, the anomaly variable, and the control variables are all nonmissing. We exclude a stock's data from the start of July of year $t$ to the end of June of year $t+1$ if the stock's price at the end of June of year $t$ is below \$1.

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[18] All FM regressions involving the failure probability are run over the 1981 to 2013 sample period. The reason is that the recursively estimated coefficients of Campbell, Hilscher, and Szilagyi's (2008) logit failure model are only available from January 1981. We thank Jens Hilscher for providing the coefficients.

### *C.2. Momentum and Profitability Anomalies*

We first study the ability of capacity overhang to explain momentum and profitability anomalies. Table VII presents the results of FM regressions on the capacity overhang estimate (Panel A), on each of the momentum and profitability anomaly variables (Panel B), and on the capacity overhang estimate and the anomaly variable (Panel C). While we do not report estimates, all FM regressions include a constant and the controls. Panel D presents the percentage change in the absolute premium of the anomaly variable (capacity overhang estimate) obtained by adding the capacity overhang estimate (anomaly variable) to the FM regression excluding it. The panel also shows the average cross-sectional correlation between the capacity overhang estimate and each of the anomaly variables.

Table VII suggests that capacity overhang helps explain momentum and profitability anomalies. Panel A shows that the capacity overhang estimate is always significantly priced in models only also including the controls, with premia and *t*-statistics consistent with those in Table VI. Further, Panel B shows that Jegadeesh and Titman's (1993) 6- and 11-month past (momentum) returns are also significantly priced in models only also including the controls, with premia of about 60 basis points per month (*t*-statistics: 2.41 and 3.17, respectively). Including capacity overhang along with the past returns and the controls, the past return premia shrink by about 30% to 40%, rendering the six-month premium insignificant and the 11-month premium significant at a lower significance level (*t*-statistic: 2.21), while the capacity overhang premium changes little (see Panel C). That the 11-month past return retains some significance in our tests supports Asness, Moskowitz, and Pedersen's (2013) claim that real options models cannot fully explain momentum anomalies, based on their finding that such anomalies exist in asset classes in which real options are not important. However, while real options models may not fully explain momentum anomalies, our evidence in this section suggests that they significantly contribute to explaining such anomalies.[19]

Turning to the profitability anomalies, Panel B shows that Lakonishok, Shleifer, and Vishny's (1994) sales growth, Haugen and Baker's (1996) asset turnover, and Campbell, Hilscher, and Szilagyi's (2008) failure probability are not significantly priced in models only also including the controls. The insignificant asset turnover premium is surprising since the variable shares a correlation of –0.47 with the capacity overhang estimate (see Panel D), consistent with asset turnover being a crude proxy for capacity overhang. In contrast, the profitability variables of Lev and Nissim (2004), Soliman (2008), Novy-Marx (2013), Fama and French (2015), and Hou, Xue, and Zhang (2015) are significantly positively priced in models only also including the controls, with *t*-statistics above 2.28. Including capacity overhang along with each anomaly variable and the controls eliminates the premia of all profitability variables

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[19] Johnson (2002) and Liu and Zhang (2014) show that other neoclassical investment models also help explain momentum anomalies in stock returns.

## Table VII
### Fama-MacBeth Regressions on Capacity Overhang, Momentum, and Profitability

The table presents the results of Fama-MacBeth (1973) regressions of single-stock returns over month $t$ on *CapacityOverhang*, momentum and profitability anomaly variables, and control variables calculated using data until the end of month $t-1$. Panel A uses *CapacityOverhang* plus the controls as exogenous variables; Panel B uses each anomaly variable plus the controls; and Panel C uses each anomaly variable, *CapacityOverhang*, and the controls. The capacity overhang estimate is calculated using gross PPE plus intangibles as the proxy for productive capacity and includes *StockVolatility* among the determinants of optimal capacity. The control variables are *MarketBeta*, *MarketSize*, and *BookToMarket*. The models also always include a constant. More details about the variables are provided in Tables CI and CII. The regressions in each column consider only observations for which all explanatory variables used in the column are available. Risk premium estimates are per month and in percent; associated $t$-statistics, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets (the estimates and $t$-statistics of the constant and the control variables are not reported). Panel D reports the percentage change in the absolute anomaly (capacity overhang) premium after controlling for *CapacityOverhang* (*AnomalyVariable*) under $\Delta$Anomaly ($\Delta$CO) Pricing. The panel also reports the average cross-sectional correlation between the anomaly variable and the capacity overhang estimate. We exclude a stock from the July of year $t$ to June of year $t+1$ sample period if the stock has a price below \$1 at the start of that period.

| | Six Month Momentum | 11 Month Momentum | Sales Growth | Asset Turnover | Profit Margin | Operating Profit | Profit | Return on Equity | Taxable Income | Failure Prob |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Anomaly Variable | | | | | |
| | | | Panel A: Regressions on Capacity Overhang and Controls | | | | | | | |
| *CapacityOverhang* | −0.861 | −0.858 | −0.827 | −0.856 | −0.868 | −0.865 | −0.865 | −0.878 | −0.859 | −1.006 |
| | [−5.36] | [−5.33] | [−4.94] | [−5.28] | [−5.37] | [−5.38] | [−5.38] | [−5.40] | [−5.96] | [−5.49] |
| | | | Panel B: Regressions on Anomaly Variable and Controls | | | | | | | |
| *AnomalyVariable* | 0.565 | 0.656 | −0.093 | 0.007 | 0.911 | 0.647 | 0.411 | 1.311 | 0.099 | 0.086 |
| | [2.41] | [3.17] | [−0.44] | [0.08] | [2.28] | [3.19] | [2.47] | [5.16] | [2.32] | [1.29] |
| | | | Panel C: Regressions on Anomaly Variable, Capacity Overhang and Controls | | | | | | | |
| *AnomalyVariable* | 0.341 | 0.455 | −0.289 | −0.243 | 0.364 | 0.258 | 0.144 | 1.042 | 0.057 | 0.195 |
| | [1.49] | [2.21] | [−1.40] | [−2.47] | [0.91] | [1.50] | [1.03] | [4.51] | [1.39] | [3.04] |
| *CapacityOverhang* | −0.878 | −0.831 | −0.851 | −1.087 | −0.880 | −0.788 | −0.830 | −0.624 | −0.849 | −1.257 |
| | [−6.04] | [−5.90] | [−5.17] | [−6.46] | [−6.13] | [−5.29] | [−5.90] | [−4.78] | [−5.94] | [−7.53] |

**Table VII**—*Continued*

|  | Anomaly Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Six Month Momentum | 11 Month Momentum | Sales Growth | Asset Turnover | Profit Margin | Operating Profit | Profit | Return on Equity | Taxable Income | Failure Prob |
|  | | | | | Panel D: Model Diagnostics | | | | | |
| ΔAnomaly Pricing | −0.40 | −0.31 | 2.11 | −34.22 | −0.60 | −0.60 | −0.65 | −0.21 | −0.43 | 1.26 |
| ΔCO Pricing | 0.02 | −0.03 | 0.03 | 0.27 | 0.01 | −0.09 | −0.04 | −0.29 | −0.01 | 0.25 |
| Correlation | −0.18 | −0.24 | −0.14 | −0.47 | −0.32 | −0.35 | −0.30 | −0.36 | −0.07 | 0.31 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

except ROE, without significantly changing the capacity overhang premium (see Panel C). The inability of capacity overhang to affect the ROE premium is surprising since the correlation between the capacity overhang estimate and ROE is –0.36, similar to the capacity overhang estimate's correlations with the other profitability variables. Interestingly, controlling for capacity overhang renders the asset turnover premium significantly negative, while it renders the failure probability premium significantly positive.

In the Internet Appendix, we show that the capacity overhang estimate based on PPE performs almost as well in explaining momentum and profitability anomalies as the estimate based on PPE plus intangibles. In contrast, the capacity overhang estimate based on total assets performs markedly worse. We also show that the inclusion of stock volatility among the optimal capacity determinants has little effect on the ability of the capacity overhang estimate to explain momentum and profitability anomalies.

### C.3. Value and Investment Anomalies

We next investigate the ability of capacity overhang to explain value and investment anomalies. Table VIII presents the results from FM regressions analogous to those in Section II.C.2 except that we replace the momentum and profitability variables with value and investment variables. The table, which is identical in design to Table VII, suggests that capacity overhang does not help explain value and investment anomalies. Panel A shows that the capacity overhang estimate is always significantly negatively priced in models only also including the controls. Further, Panel B suggests that, of the value anomalies, Fama and French's (1992) book-to-market ratio is significantly positively priced in models only also including the controls (*t*-statistic: 4.20), while DeBondt and Thaler's (1985) long-term past returns are not significantly priced. Of the investment anomalies, both the accruals variables and the investment variables are significantly negatively priced, with *t*-statistics between –2.47 and –3.36 for the accruals variables and between –3.81 and –5.89 for the investment variables.

Including capacity overhang along with each anomaly variable and the controls does not greatly influence the pricing of the book-to-market ratio and the investment variables (see Panel C), consistent with the correlations between the capacity overhang estimate and these anomaly variables being close to zero (see Panel D). Including capacity overhang along with the long-term past returns and the accruals variables renders the long-term past return premia significantly negative (with *t*-statistics of –3.11 for the two-year return and –1.97 for the five-year return) and raises the significance of the accruals premia (see Panel C).

In the Internet Appendix, we show that capacity overhang estimates based on other installed capacity proxies and either including or excluding stock volatility perform no better in explaining value and investment anomalies than the estimate reported in the paper.

**Table VIII**

**Fama-MacBeth Regressions on Capacity Overhang, Value, and Investment Variables**

The table presents the results of Fama-MacBeth (1973) regressions of single-stock returns over month $t$ on *CapacityOverhang*, value and investment anomaly variables, and control variables calculated using data until the end of month $t − 1$. Panel A uses *CapacityOverhang* plus the controls as exogenous variables; Panel B uses each anomaly variable plus the controls; and Panel C uses each anomaly variable, *CapacityOverhang*, and the controls. The capacity overhang estimate is calculated using gross PPE plus intangibles as the proxy for productive capacity and includes *StockVolatility* among the determinants of optimal capacity. The control variables are *MarketBeta*, *MarketSize*, and *BookToMarket*. The models also always include a constant. More details about the variables are provided in Tables CI and CII. The regressions in each column consider only observations for which all explanatory variables used in the column are available. Risk premium estimates are per month and in percent; associated $t$-statistics, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets (the estimates and $t$-statistics of the constant and the control variables are not reported). Panel D reports the percentage change in the absolute anomaly (capacity overhang) premium after controlling for *CapacityOverhang* (*AnomalyVariable*) under Δ*Anomaly* (Δ*CO*) Pricing. The panel also reports the average cross-sectional correlation between the anomaly variable and the capacity overhang estimate. We exclude a stock from the July of year $t$ to June of year $t + 1$ sample period if the stock has a price below \$1 at the start of that period.

| | | | Past | | | | | | | |
| | Book to Market | Past Return (−12, −35) | Return (−1, −59) | Operating Accruals | Total Accruals | Percent Accruals | Abn. Investment | Investment Growth | PPE Change | Asset Growth |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Anomaly Variable | | | | |
| | | | | Panel A: Regressions on Capacity Overhang and Controls | | | | | | |
| *CapacityOverhang* | −0.865 | −0.817 | −0.842 | −0.860 | −0.859 | −0.862 | −0.871 | −0.875 | −0.852 | −0.853 |
| | [−5.38] | [−4.95] | [−4.95] | [−5.32] | [−5.32] | [−5.34] | [−5.38] | [−5.39] | [−5.27] | [−5.29] |
| | | | | Panel B: Regressions on Anomaly Variable and Controls | | | | | | |
| *AnomalyVariable* | 0.376 | −0.249 | −0.055 | −1.149 | −0.703 | −0.045 | −0.122 | −0.162 | −1.023 | −0.842 |
| | [4.20] | [−1.86] | [−0.52] | [−3.05] | [−2.47] | [−3.36] | [−3.81] | [−4.50] | [−5.41] | [−5.89] |
| | | | | Panel C: Regressions on Anomaly Variable, Capacity Overhang, and Controls | | | | | | |
| *AnomalyVariable* | 0.388 | −0.379 | −0.198 | −1.745 | −0.993 | −0.065 | −0.131 | −0.168 | −0.954 | −0.891 |
| | [4.37] | [−3.11] | [−1.97] | [−5.31] | [−4.01] | [−4.92] | [−4.29] | [−4.97] | [−5.19] | [−6.51] |
| *CapacityOverhang* | −0.865 | −0.937 | −0.995 | −0.931 | −0.897 | −0.909 | −0.872 | −0.882 | −0.827 | −0.869 |
| | [−5.38] | [−6.55] | [−6.89] | [−6.01] | [−5.75] | [−5.63] | [−5.40] | [−5.51] | [−5.14] | [−5.58] |

(*Continued*)

**Table VIII**—*Continued*

|  | Book to Market | Past Return (−12, −35) | Past Return (−1, −59) | Operating Accruals | Total Accruals | Percent Accruals | Abn. Investment | Investment Growth | PPE Change | Asset Growth |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Anomaly Variable* | | | | |
| | | | | | | Panel D: Model Diagnostics | | | | |
| ΔAnomaly Pricing | 0.03 | 0.52 | 2.63 | 0.52 | 0.41 | 0.45 | 0.07 | 0.04 | −0.07 | 0.06 |
| ΔCO Pricing | 0.00 | 0.15 | 0.18 | 0.08 | 0.04 | 0.05 | 0.00 | 0.01 | −0.03 | 0.02 |
| Correlation | 0.10 | −0.24 | −0.33 | −0.17 | −0.14 | −0.12 | −0.03 | −0.03 | 0.02 | −0.06 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

<div align="center">

**Table IX**

**Fama-MacBeth Regressions on Capacity Overhang and ROE**

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The table presents the results of Fama-MacBeth (1973) regressions of single-stock returns over month $t$ on *ReturnOnEquity*, *CapacityOverhang*, and earnings surprise variables calculated using data until the end of month $t-1$. The capacity overhang estimate is calculated using gross PPE plus intangibles as the proxy for productive capacity and includes *StockVolatility* among the determinants of optimal capacity. The earnings surprise variables are *EarningsAnnouncementReturn* and *StandardizedUnexpectedEarnings*. More details about the variables are provided in Tables CI and CII. The table only considers observations for which all explanatory variables are available. Risk premium estimates are per month and in percent; associated $t$-statistics, calculated using Newey and West's (1987) formula with a lag length of 12 months, are in square brackets. We exclude a stock from the July of year $t$ to June of year $t+1$ sample period if the stock has a price below \$1 at the start of that period.

| | Regression Model | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *ReturnOnEquity* | 0.611 | 0.000 | | | −0.015 |
| | [2.88] | [0.00] | | | [−0.08] |
| *CapacityOverhang* | | | −0.675 | −0.408 | −0.379 |
| | | | [−3.76] | [−2.36] | [−2.64] |
| *EarningsAnnouncementReturn* | | 4.983 | | 4.892 | 4.872 |
| | | [14.39] | | [14.36] | [13.99] |
| *StandardizedUnexpectedEarnings* | | 0.268 | | 0.239 | 0.242 |
| | | [9.61] | | [8.08] | [8.75] |
| Constant | 1.278 | 1.276 | 0.809 | 1.036 | 1.077 |
| | [4.49] | [4.47] | [2.18] | [2.78] | [3.02] |

## *C.4. Return on Equity*

Given the ability of capacity overhang to explain the pricing of other profitability variables in Section II.C.2, we find it surprising that it cannot explain the pricing of Hou, Xue, and Zhang's (2015) ROE. Novy-Marx (2016) offers a possible explanation for this finding, arguing that the ROE variable is not a profitability proxy, but instead an "earnings surprise proxy-in-disguise." To test this claim, Table IX presents the results from FM regressions of single-stock returns over month $t$ on the month $t-1$ values of ROE, the capacity overhang estimate, and Novy-Marx's (2016) two earnings surprise variables, namely, the earnings announcement return and standardized unexpected earnings. See Table CII in Appendix C for the definitions of the earnings surprise variables. As before, we include an observation in the FM regressions only if ROE, the capacity overhang estimate, and the two earnings surprise variables are all nonmissing. Also, as before, we exclude a stock's data from the start of July of year $t$ to the end of June of year $t+1$ if the stock's price at the end of June of year $t$ is below \$1.

Table IX supports Novy-Marx's (2016) claim. While the ROE premium is a significant 61 basis points per month in the model excluding either earnings surprise variable ($t$-statistic: 2.88; see column (1)), it is virtually zero in the model including both the earnings announcement return and the standardized

earnings surprise (see column (2)). In contrast, the earnings surprise variables reduce the capacity overhang premium by only about 40%, without eliminating its significance (see columns (3) and (4)). When we jointly include capacity overhang, ROE, and the earnings variables in the model in column (5), we find that the capacity overhang premium remains significantly negative (*t*-statistic: –2.64), while the ROE premium is insignificant (*t*-statistic: –0.08). Thus, while the pricing ability of ROE comes almost entirely from earnings surprises, capacity overhang contains important incremental pricing information.

## III. Conclusion

Prior theoretical studies suggest that real options models of the firm are able to produce a variety of expected return-capacity overhang relations, with different relations offering the prospect of explaining different stock anomalies. Despite strong theoretical foundations, however, there is little empirical research on the expected return-capacity overhang relation and its implications for stock anomalies. We try to close this gap in the literature. We use a stochastic frontier model to derive a stock-level estimate of capacity overhang. Using capacity overhang estimates derived from the model in portfolio sorts and FM regressions, we study the pricing of capacity overhang and its ability to explain stock anomalies. Our empirical work suggests that capacity overhang is significantly and near-monotonically negatively related to the cross section of stock returns, in line with real options models in which the firm owns important divestment options. The negative relation persists among small and large stocks, firms with more or less reversible investments, and in good and bad economic states. Our empirical work further suggests that capacity overhang helps explain momentum and profitability anomalies in stock returns, but not value and investment anomalies.

## Appendix A: Model Solution

The value of the production option indexed by $\theta$ and $K$, $\Delta V(\theta, K)$, must satisfy the ordinary differential equation (see, for example, Dixit and Pindyck (1994))

$$\frac{1}{2}\sigma^2\theta^2\frac{\partial^2\Delta V(\theta, K)}{\partial\theta^2} + (r-\delta)\theta\frac{\partial\Delta V(\theta, K)}{\partial\theta} - r\Delta V(\theta, K) + C(\theta, K) = 0, \quad \text{(A1)}$$

where $C(\theta, K)$ is the profit produced by that production option.

Let $\theta'$ denote the demand level at or below which the firm decides to sell off the production option. When demand is above this level but below the level at which the firm switches the production option on (i.e., $\theta' \leq \theta \leq (2\gamma + c_2)K + c_1$),

the unit profit of the option is zero (i.e., $C(\theta, K) = 0$). In this case, the value of the production option is of the form

$$\Delta V(\theta, K) = b_1 \theta^{\beta_1} + b_3 \theta^{\beta_2}, \tag{A2}$$

where

$$\beta_1 = -\frac{(r - \delta - \sigma^2/2)}{\sigma^2} + \frac{1}{\sigma^2}[(r - \delta - \sigma^2/2)^2 + 2r\sigma^2]^{(1/2)} > 1, \tag{A3}$$

$$\beta_2 = -\frac{(r - \delta - \sigma^2/2)}{\sigma^2} - \frac{1}{\sigma^2}[(r - \delta - \sigma^2/2)^2 + 2r\sigma^2]^{(1/2)} < 0, \tag{A4}$$

and $b_1$ and $b_3$ are free parameters. When $\theta \geq (2\gamma + c_2)K + c_1$, the firm switches the production option on, and the unit profit of the production option is $C(\theta, K) = \theta - (2\gamma + c_2)K - c_1$. In this case, the value of the production option is of the form

$$\Delta V(\theta, K) = b_2 \theta^{\beta_2} + \frac{\theta}{\delta} - \frac{(2\gamma + c_2)K + c_1}{r}, \tag{A5}$$

where $b_2$ is a free parameter and we use the boundary condition $\lim_{\theta \to +\infty} \Delta V(\theta, K) = (\theta/\delta) - ((2\gamma + c_2)K + c_1)/r$ to rule out the independent solution involving $\beta_1$.

We determine the values of $b_1$, $b_2$, $b_3$, and $\theta'$ using the following value-matching and smooth-pasting conditions at the optimal capacity switch-on demand threshold, $\theta^P \equiv (2\gamma + c_2)K + c_1$, and the optimal capacity divestment demand threshold, $\theta'$:

$$b_1(\theta^P)^{\beta_1} + b_3(\theta^P)^{\beta_2} = b_2(\theta^P)^{\beta_2} + \frac{(\theta^P)}{\delta} - \frac{(2\gamma + c_2)K + c_1}{r}, \tag{A6}$$

$$b_1\beta_1(\theta^P)^{\beta_1-1} + b_3\beta_2(\theta^P)^{\beta_2-1} = b_2\beta_2(\theta^P)^{\beta_2-1} + \frac{1}{\delta}, \tag{A7}$$

$$b_1(\theta')^{\beta_1} + b_3(\theta')^{\beta_2} = \Delta F(\theta', K) + d, \tag{A8}$$

$$b_1\beta_1(\theta')^{\beta_1-1} + b_3\beta_2(\theta')^{\beta_2-1} = \frac{\partial \Delta F(\theta', K)}{\partial \theta'}, \tag{A9}$$

where $\Delta F(\theta', K)$ is the value of the growth option indexed by $\theta$ and $K$ at the optimal divestment demand threshold $\theta'$. Using equations (A6) and (A7), we find that

$$b_1 = \frac{r - \beta_2(r - \delta)}{r\delta(\beta_1 - \beta_2)}[(2\gamma + c_2)K + c_1]^{1-\beta_1} > 0, \tag{A10}$$

$$b_2 - b_3 = \frac{r - \beta_1(r - \delta)}{r\delta(\beta_1 - \beta_2)}[(2\gamma + c_2)K + c_1]^{1-\beta_2} > 0. \tag{A11}$$

The value of the growth option indexed by $\theta$ and $K$, $\Delta F(\theta, K)$, must satisfy

$$\frac{1}{2}\sigma^2\theta^2\frac{\partial^2 \Delta F(\theta, K)}{\partial \theta^2} + (r - \delta)\theta\frac{\partial \Delta F(\theta, K)}{\partial \theta} - r\Delta F(\theta, K) = 0, \tag{A12}$$

which implies that the value of that growth option is of the form

$$\Delta F(\theta, K) = a\theta^{\beta_1}, \tag{A13}$$

where $a$ is a free parameter and we use the boundary condition $\lim_{\theta \to 0} \Delta F(\theta, K) = 0$ to rule out the independent solution involving $\beta_2$. We use the following value-matching and smooth-pasting conditions at the demand level at which the growth option is optimally exercised and converted, $\theta^*$, to determine the values of both $a$ and $\theta^*$:

$$b_2(\theta^*)^{\beta_2} + \frac{\theta^*}{\delta} - \frac{(2\gamma + c_2)K + c_1}{r} - k = a(\theta^*)^{\beta_1}, \tag{A14}$$

$$b_2\beta_2(\theta^*)^{\beta_2-1} + \frac{1}{\delta} = a\beta_1(\theta^*)^{\beta_1-1}. \tag{A15}$$

Conditional on $\theta^*$, we can solve equation (A15) for $a$:

$$a = b_2\frac{\beta_2}{\beta_1}(\theta^*)^{\beta_2-\beta_1} + \frac{(\theta^*)^{1-\beta_1}}{\beta_1\delta}. \tag{A16}$$

To complete the solution, we need to solve the following system of three equations in the three unknown parameters $b_2$, $\theta'$, and $\theta^*$:

$$b_1(\theta')^{\beta_1} + (b_2 - b_d)(\theta')^{\beta_2} = a(\theta')^{\beta_1} + d, \tag{A17}$$

$$b_1\beta_1(\theta')^{\beta_1-1} + (b_2 - b_d)\beta_2(\theta')^{\beta_2-1} = a\beta_1(\theta')^{\beta_1-1}, \tag{A18}$$

$$b_2(\theta^*)^{\beta_2} + \frac{\theta^*}{\delta} - \frac{(2\gamma + c_2)K + c_1}{r} - k = a(\theta^*)^{\beta_1}, \tag{A19}$$

where the first two equations follow from equations (A8) and (A9), respectively, with $b_d \equiv b_2 - b_3$ given in (A11), and the last equation is equation (A14). Conditional on the value of $a$ given in equation (A16), we can solve equations (A17) and (A18) for $\theta'$ and $b_2$:

$$\theta' = \left(\frac{\beta_2 d}{(a - b_1)(\beta_1 - \beta_2)}\right)^{\frac{1}{\beta_1}}, \tag{A20}$$

$$b_2 = (a - b_1)\left(\frac{\beta_2 d}{(a - b_1)(\beta_1 - \beta_2)}\right)^{1 - \frac{\beta_2}{\beta_1}} + d\left(\frac{\beta_2 d}{(a - b_1)(\beta_1 - \beta_2)}\right)^{-\frac{\beta_2}{\beta_1}} + b_d. \quad \text{(A21)}$$

Substituting the solutions for $a$ and $b_2$ into equation (A19), we numerically solve the resulting implicit function of the optimal investment demand threshold for $\theta^*$.

## Appendix B: Proof of Proposition 1

When capacity cannot be sold at a positive price ($d = 0$), it follows from equations (A20) and (A21) that $b_3$ and $\theta'$ are zero and that the model collapses to Pindyck's (1988) model. We first derive two lemmas that are helpful in proving Proposition 1.

LEMMA 1: *The strict ordering of functions $\Delta V(\theta, K)$ and $\Delta F(\theta, K)$, given by*

$$\Delta V(\theta, K) > \Delta F(\theta, K), \quad \text{(B1)}$$

*holds over the entire domain of $\theta$ and $K$.*

PROOF OF LEMMA 1: Lemma 1 follows from the result that a call option must be worth less than its underlying asset. Assume the opposite, that is, that $\Delta V(\theta, K) \leq \Delta F(\theta, K)$. In this case, an arbitrageur could purchase the underlying asset and short-sell the option, realizing an immediate cash flow of $\Delta F(\theta, K) - \Delta V(\theta, K) \geq 0$. When the option is exercised, the arbitrageur transfers the underlying asset, receiving a cash flow of $k$ in return. Thus, the arbitrageur earns a zero or positive cash flow today, an operating profit equal to $\max(\theta - (2\gamma + c_2) - c_1, 0)$ per unit of time at each time $t$ until exercise, and a positive cash flow upon exercise. Ruling out arbitrage opportunities, it must be the case that $\Delta V(\theta, K) > \Delta F(\theta, K)$. ∎

LEMMA 2: *The elasticity of an idle production option or an unexercised growth option, $\beta_1$, is greater than or equal to the elasticity of a used production option $(b_2\beta_2\theta^{\beta_2} + \theta/\delta)/\Delta V(\theta, K)$.*

PROOF OF LEMMA 2: The lemma claims that

$$\beta_1 \geq \frac{b_2\beta_2\theta^{\beta_2} + \theta/\delta}{b_2\theta^{\beta_2} + \theta/\delta - [(2\gamma + c_2)K + c_1]/r} \quad \text{(B2)}$$

over the interval $\theta \in \{(2\gamma + c_2)K + c_1, \infty\}$. To see that this inequality holds, multiply by $\Delta V(\theta, K) = b_2\theta^{\beta_2} + \theta/\delta - [(2\gamma + c_2)K + c_1]/r > 0$ and rearrange:

$$(\beta_1 - \beta_2)b_2\theta^{\beta_2} + (\beta_1 - 1)\theta/\delta - \beta_1[(2\gamma + c_2)K + c_1]/r) \geq 0. \quad \text{(B3)}$$

Substituting the solution of $b_2$ from Appendix A into the inequality, we obtain

$$\frac{r - \beta_1(r - \delta)}{r\delta}[(2\gamma + c_2)K + c_1]^{1 - \beta_2}\theta^{\beta_2} + (\beta_1 - 1)\theta/\delta - \beta_1[(2\gamma + c_2)K + c_1]/r) \geq 0.$$

$$\text{(B4)}$$

Multiplying by $r > 0$ and $[(2\gamma + c_2)K + c_1]^{(\beta_2-1)}\theta^{(-\beta_2)} > 0$ and rearranging, we obtain

$$\frac{r - \beta_1(r - \delta)}{\delta} + \frac{r(\beta_1 - 1)}{\delta}\left(\frac{\theta}{(2\gamma + c_2)K + c_1}\right)^{(1-\beta_2)} - \beta_1\left(\frac{\theta}{(2\gamma + c_2)K + c_1}\right)^{(-\beta_2)} \geq 0. \tag{B5}$$

Inequality (B5) holds if its left-hand side (i) is zero at $\theta = \theta^P \equiv (2\gamma + c_2)K + c_1$ and (ii) increases with $\theta$ for $\theta$ above $\theta^P$. To see that condition (i) holds, plug the definition of $\theta^P$ into the left-hand side, noting that $\beta_1 = \frac{r - \beta_1(r-\delta)}{\delta} + \frac{r(\beta_1-1)}{\delta}$. To see that condition (ii) holds, note that the partial derivative of the left-hand side with respect to $\theta$ is

$$\frac{r(1 - \beta_2)(\beta_1 - 1)}{\delta[(2\gamma + c_2)K + c_1]}\left(\frac{\theta}{(2\gamma + c_2)K + c_1}\right)^{-\beta_2} + \frac{\beta_1\beta_2}{(2\gamma + c_2)K + c_1}\left(\frac{\theta}{(2\gamma + c_2)K + c_1}\right)^{-\beta_2-1}. \tag{B6}$$

This expression is positive if and only if

$$\frac{r(1 - \beta_2)(\beta_1 - 1)}{\delta} + \beta_1\beta_2\left(\frac{\theta}{(2\gamma + c_2)K + c_1}\right)^{-1} > 0, \tag{B7}$$

where $\frac{r(1-\beta_2)(\beta_1-1)}{\delta} > 0$ and $\beta_1\beta_2(\frac{\theta}{(2\gamma+c_2)K+c_1})^{-1} < 0$ (as $\beta_2 < 0$). Evaluating the partial derivative at $\theta = \theta^P$, we obtain $\frac{r}{\delta}(\beta_1 + \beta_2 - \beta_1\beta_2 - 1) + \beta_1\beta_2$. Using the definitions of $\beta_1$ and $\beta_2$ in Appendix A, we find that $\beta_1 + \beta_2 = -\frac{2(r-\delta-\sigma^2/2)}{\sigma^2}$ and $\beta_1\beta_2 = -\frac{2r}{\sigma^2}$. Substituting back into the partial derivative, we find that $\frac{r}{\delta}(-\frac{2(r-\delta-\sigma^2/2)}{\sigma^2} + \frac{2r}{\sigma^2} - 1) - \frac{2r}{\sigma^2} = 0$, which implies that the partial derivative is zero if $\theta = \theta^P$. Raising $\theta$ above $\theta^P$, only the negative summand in inequality (B7) changes, from $\beta_1\beta_2$ to $\beta_1\beta_2((2\gamma + c_2)K + c_1)/\theta$. When $\theta > \theta^P$, $((2\gamma + c_2)K + c_1)/\theta < 1$, decreasing the magnitude of the negative summand on the left-hand side of inequality (B7) and ensuring that the inequality is fulfilled when demand $\theta$ exceeds $\theta^P$. ∎

PROOF OF PROPOSITION 1: The expected excess return of a firm satisfying $K^* < \bar{K} \leq (\theta - c_1)/(2\gamma + c_2)$ is given by

$$E[r_A] - r = \frac{1}{W}\left(\beta_2\theta^{\beta_2}\int_0^{\bar{K}} b_2(v)dv + \theta/\delta\int_0^{\bar{K}} dv + \beta_1\int_{\bar{K}}^{\infty} \Delta F(\theta, v)dv\right), \tag{B8}$$

where, without loss of generality, we set $(\mu - r)$ equal to unity.

The partial derivative of the expected excess return with respect to capacity, $\bar{K}$, is

$$\frac{\partial \mathrm{E}[r_A] - r}{\partial \bar{K}} = \frac{1}{W^2} \left[ \left( \beta_2 \theta^{\beta_2} b_2(\bar{K}) + \theta/\delta - \beta_1 \Delta F(\theta, \bar{K}) \right) \times W - \left( \Delta V(\theta, \bar{K}) - \Delta F(\theta, \bar{K}) \right) \right.$$

$$\left. \times \left( \beta_2 \theta^{\beta_2} \int_0^{\bar{K}} b_2(v) dv + \theta/\delta \int_0^{\bar{K}} dv + \beta_1 \int_{\bar{K}}^\infty \Delta F(\theta, v) dv \right) \right], \qquad \text{(B9)}$$

or, alternatively,

$$\frac{\Delta V(\theta, \bar{K})}{W} \left( \frac{b_2(\bar{K}) \beta_2 \theta^{\beta_2} + \theta/\delta}{\Delta V(\theta, \bar{K})} - (\mathrm{E}[r_A] - r) \right) - \frac{\Delta F(\theta, \bar{K})}{W} \left( \beta_1 - (\mathrm{E}[r_A] - r) \right). \quad \text{(B10)}$$

Lemma 2 suggests that $\beta_1 - (\mathrm{E}[r_A] - r) > 0$. As a result, a sufficient condition for the partial derivative to be negative is $\frac{b_2(\bar{K}) \beta_2 \theta^{\beta_2} + \theta/\delta}{\Delta V(\theta, \bar{K})} \leq \mathrm{E}[r_A] - r$. Since we can interpret $\frac{b_2(\bar{K}) \beta_2 \theta^{\beta_2} + \theta/\delta}{\Delta V(\theta, \bar{K})}$ as the elasticity of the marginal production option and $\mathrm{E}[r_A] - r$ as the (scaled) value-weighted average of the elasticities of the firm's options, the firm's expected return decreases with capacity overhang if the marginal production option's risk is below the risk of the firm.

The expected excess return of a firm satisfying $\bar{K} \geq (\theta - c_1)/(2\gamma + c_2)$ is given by

$$\mathrm{E}[r_A] - r = \frac{1}{W} \left( \int_0^{\frac{\theta - c_1}{2\gamma + c_2}} \left( b_2(v) \beta_2 \theta^{\beta_2} + \theta/\delta \right) dv + \beta_1 \int_{\frac{\theta - c_1}{2\gamma + c_2}}^{\bar{K}} \Delta V(\theta, v) dv + \beta_1 \int_{\bar{K}}^\infty \Delta F(\theta, v) dv \right).$$

$$\text{(B11)}$$

The partial derivative of the expected excess return with respect to capacity, $\bar{K}$, is

$$\frac{\partial \mathrm{E}[r_A] - r}{\partial \bar{K}} = \frac{1}{W^2} \left[ \beta_1 (\Delta V(\theta, \bar{K}) - \Delta F(\theta, \bar{K})) \times W - (\Delta V(\theta, \bar{K}) - \Delta F(\theta, \bar{K})) \right.$$

$$\times \left( \int_0^{\frac{\theta - c_1}{2\gamma + c_2}} (b_2(v) \beta_2 \theta^{\beta_2} + \theta/\delta) dv + \beta_1 \int_{\frac{\theta - c_1}{2\gamma + c_2}}^{\bar{K}} \Delta V(\theta, v) dv \right.$$

$$\left. \left. + \beta_1 \int_{\bar{K}}^\infty \Delta F(\theta, v) dv \right) \right], \qquad \text{(B12)}$$

or, alternatively,

$$\frac{\partial \mathrm{E}[r_A] - r}{\partial \bar{K}} = \left( \frac{\Delta V(\theta, \bar{K})}{W} - \frac{\Delta F(\theta, \bar{K})}{W} \right) (\beta_1 - (\mathrm{E}[r_A] - r)). \qquad \text{(B13)}$$

Lemma 1 suggests that $(\Delta V(\theta, \bar{K}) - \Delta F(\theta, \bar{K})) > 0$. Equation (4) shows that $\mathrm{E}[r_A] - r$ is the scaled value-weighted average of the elasticities of the production and growth options owned by the firm. Lemma 2 suggests that $\beta_1$ is the maximum

possible elasticity, which implies that $(\beta_1 - (E[r_A] - r)) > 0$. Thus, the partial derivative is unambiguously positive. ∎

# Appendix C: Variable Definitions

## Table CI
## Analysis Variables

The table defines all variables used in our tests except the anomaly variables. In our asset pricing tests, we use *CapacityOverhang*, *GDPGrowth*, *IndProductionGrowth*, and *PastMarketReturn* values from the end of month $t-1$ to condition single-stock returns over month $t$; *MarketBeta* and *MarketSize* values from June of year $t$ to condition monthly single-stock returns over the period from July of year $t$ to June of year $t+1$; and time-invariant *InvReversibility* values to condition single-stock returns over month $t$. We show the mnemonics assigned to the input variables by the data providers (CRSP and Compustat) in parentheses.

| Variable Name | Variable Definition |
|---|---|
| | Panel A: Capacity Overhang Variables |
| *CapacityOverhang* | Log of the spread between a stock's installed production capacity and its optimal production capacity, recursively estimated using a stochastic frontier model with industry fixed effects. |
| *InstalledCapacity* | (i) Log of the sum of gross property, plant, and equipment (ppegt or ppegtq) and intangible assets (intan or intanq). |
| | (ii) Log of gross property, plant, and equipment (ppegt or ppegtq). |
| | (iii) Log of total assets (at or atq). |
| *Sales* | Log of sales over the prior four fiscal quarters (sale or saleq). |
| *COGS* | Log of COGS over the prior four fiscal quarters (cogs or cogsq). |
| *SGA* | Log of SGA costs over the prior four quarters (xsga or xsgaq). |
| *StockVolatility* | Log of the volatility of daily returns (ret) over the prior 12 months. |
| *MarketBeta* | Sum of slope coefficients from a stock-level regression of excess stock returns (ret) on current, one-day lagged, and the sum of two-, three-, and four-day lagged excess market returns, where the regression is run using daily data over the prior 12 months (see Lewellen and Nagel (2006) for more details about the methodology). |
| *RiskfreeRate* | Three-month Treasury bill rate (see Kenneth French's website). |
| *RecentSalesDecline* | Percentage decrease in sales (sale or saleq) over the most recent four fiscal quarters; the variable is set to zero if the decrease is negative. |
| *DistantSalesDecline* | Percentage decrease in sales (sale or saleq) from a stock's historical maximum of sales, measured 12 months ago, to its sales 12 months ago; the variable is set to zero if the decrease is negative. |
| *LossDummy* | Dummy set equal to one if a firm ran a loss (negative ni or niq) over the prior four fiscal quarters; otherwise, the variable is set to zero. |
| | Panel B: Investment Reversibility Variables |
| *InvReversibility* | The inverse of the time-series volatility of the cross-sectional median of *CapacityOverhang* per two-digit SIC code industry assigned to all stocks in an industry, where volatility is taken over the full sample period and the variable is calculated only for industries consistently featuring 10 or more stocks (see Cooper, Wu, and Gerard (2005)). |

(*Continued*)

**Table CI**—*Continued*

| Variable Name | Variable Definition |
|---|---|
| | Panel C: State Variables |
| *GDPGrowth* | Percent change in GDP over the prior four quarters. |
| *IndProductionGrowth* | Percent change in industrial production over the prior 12 months. |
| *PastMarketReturn* | Cumulative market return over the prior 36 months. |
| | Panel D: Other Variables |
| $\Delta CAPX$ | Net percent change in capital expenditures (capx) from the fiscal year ending in calendar year $t-2$ to that ending in year $t-1$. |
| $\Delta(PPE+Intangibles)$ | Net percent change in PPE (ppegt) + intangibles (intan) from the fiscal year ending in calendar year $t-2$ to that ending in year $t-1$. |
| *CapacityUtilization* | Industry capacity utilization rates obtained from BEA surveys. |
| *MarketSize* | Log of the product of the stock price (abs(prc)) times common shares outstanding (shrout). |
| | Panel E: Campbell (1996) Industry Definitions |
| Petroleum | SIC Codes: 13, 29. |
| Consumer durables | SIC Codes: 25, 30, 36-37, 50, 55, 57. |
| Basic goods | SIC Codes: 10, 12, 14, 24, 26, 28, 33. |
| Food/tobacco | SIC Codes: 1, 20, 21, 54. |
| Construction | SIC Codes: 15-17, 32, 52. |
| Capital goods | SIC Codes: 34-35, 38. |
| Transport | SIC Codes: 40-42, 44, 45, 47. |
| Textiles/trade | SIC Codes: 22-23, 31, 51, 53, 56, 59. |
| Services | SIC Codes: 72-73, 75, 80, 82, 89. |
| Leisure | SIC Codes: 27, 58, 70, 78-79. |

**Table CII**
**Anomaly Variables**

The table defines the anomaly variables used in our tests. In our asset pricing tests, we update the variables indexed by "M" on a monthly basis and use their values to condition single-stock returns over month $t+1$. We update the variables indexed by "A" on an annual basis and use their values to condition (monthly) single-stock returns over the period from July of year $t$ to June of year $t+1$. We set the variables indexed by "MR" to the values from their most recent earnings announcement date (Compustat item: rdq) and use these to condition single-stock returns over month $t+1$. We show the mnemonics assigned to the input variables by the data providers (CRSP and Compustat) in parentheses.

| Variable Name | Variable Definition |
|---|---|
| | Panel A: Momentum Variables |
| *SixMonthMom* (M) | Log of the compounded stock return (ret) over the period from month $t-6$ to month $t-1$ (see Jegadeesh and Titman (1993)). |
| *ElevenMonthMom* (M) | Log of the compounded stock return (ret) over the period from month $t-11$ to month $t-1$ (see Jegadeesh and Titman (1993)). |

(*Continued*)

**Table CII**—*Continued*

| Variable Name | Variable Definition |
| --- | --- |
| | Panel B: Profitability Variables |
| *SalesGrowth* (A) | Weighted average of the sales (sale) growth decile to which a stock belonged over the previous five years, where sales growth is calculated from the fiscal year-end in calendar year $t - j - 1$ to that in calendar year $t - j$ and the average is calculated as $\sum_{j=1}^{5} \frac{6-j}{150} \times$ Sales Growth Decile$(t - j)$ (see Lakonishok, Shleifer, and Vishny (1994)). |
| *AssetTurnover* (A) | Log of the ratio of sales (sale) to total assets (at), where the variables are from the fiscal year-end in calendar year $t - 1$ (see Haugen and Baker (1996)). |
| *ProfitMargin* (A) | Ratio of operating income after depreciation (oiadp) to sales (sale), where the variables are from the fiscal year-end in calendar year $t - 1$ (see Soliman (2008)). |
| *OperatingProfit* (A) | Ratio of gross profits (sale minus cogs) to total assets (at), where the variables are from the fiscal year-end in calendar year $t - 1$ (see Novy-Marx (2013)). |
| *Profit* (A) | Ratio of sales (sale) net of costs of goods sold (cogs), selling, general, and administrative expenses (xsge), 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, prfstck, or zero, in that order of availability) and the variables are from the fiscal year-end in calendar year $t - 1$ (see Fama and French (2015)). |
| *ReturnOnEquity* (MR) | The ratio of quarterly income before extraordinary items (ibq) to the quarterly book value of equity, where the book value of equity is shareholders' equity (seqq, ceqq+pstkq, or atq–ltq, in that order of availability) plus deferred taxes and investment tax credits (txditcq, zero if missing) minus the book value of preferred stock (pstkrq, zero if missing). Quarterly income is from the latest earnings announcement date (rdq), while all other variables are from the one before. The variable is set to missing if the earnings announcement date is more than six months after the earnings date (see Hou, Xue, and Zhang (2015)). |
| *TaxableIncome* (A) | The ratio of pretax (pi) to net income (ni), where the variables are from the fiscal year-end in year $t - 1$ (see Lev and Nissim (2004)). |
| *FailureProb* (MR) | The probability of a stock failing (i.e., filing for bankruptcy, defaulting, or being delisted for performance reasons) over the coming 12 months, calculated from a logit model estimated using data available until month $t$ and using market and accounting variables such as net income, total liabilities, and stock volatility as failure predictors (see Campbell, Hilscher, and Szilagyi (2008)). |
| | Panel C: Value Variables |
| *BookToMarket* (A) | Log of the ratio of the book value of equity to the market value of equity (abs(prc) × 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) and the variables are from the fiscal year-end in calendar year $t - 1$ (see Fama and French (1992)). |

(*Continued*)

**Table CII**—*Continued*

| Variable Name | Variable Definition |
|---|---|
| *PastRet(−12,−35)* (M) | Log of the compounded stock return (ret) over the period from month $t − 35$ to month $t − 12$ (see DeBondt and Thaler (1985) and Fama and French (1996)). |
| *PastRet(−1,−59)* (M) | Log of the compounded stock return (ret) over the period from month $t − 59$ to month $t − 1$ (see DeBondt and Thaler (1985) and Fama and French (1996)). |

| | Panel D: Investment Variables |
|---|---|
| *OperatingAccruals* (A) | *Pre-1998*: Change in current assets (atc) net of cash (che) minus the change in current liabilities (lct) net of debt included in current liabilities (dlc, zero if missing) and of income taxes payable (txp, zero if missing) minus depreciation and amortization (dp, zero if missing), where the changes are calculated from the fiscal year-end in calendar year $t − 2$ to the fiscal year-end in calendar year $t − 1$; *post-1998*: net income (ni) minus net cash flow from operations (oancf). The pre- and post-1998 variables are scaled by total assets from the fiscal year-end in calendar year $t − 2$ (see Sloan (1996), Hribar and Collins (2002), and Hou, Xue, and Zhang (2015)). |
| *TotalAccruals* (A) | *Pre-1998*: Change in net noncash working capital plus the change in net noncurrent operating assets plus the change in net financial assets, where net noncash working capital is current assets (atc) net of cash and short-term investments (che) minus current liabilities (lct) net of debt in current liabilities (dlc, zero if missing); net noncurrent operating assets is total assets (at) net of current assets (atc) and of investment and advances (ivoa, zero if missing) minus total liabilities (lt) net of current liabilities (ltc) and of long-term debt (ltcc, zero if missing); and net financial assets is the sum of short-term investments (ivst, zero if missing) and long-term investments (ivoa, zero if missing) minus the sum of long-term debt (dltt, zero if missing), debt in current liabilities (dlc, zero if missing), and preferred stock (pstk, zero if missing), where the changes are calculated from the fiscal year-end in calendar year $t − 2$ to the fiscal year-end in calendar year $t − 1$; *post-1998*: net income (ni) minus sum of total operating, investing, and financing cash flows (oancf, invcf, and fincf) plus sales of stock (sstk, zero if missing) minus stock repurchases and dividends (prstkc and dv, zero if missing). The pre- and post-1998 variables are scaled by total assets from the fiscal year-end in calendar year $t − 2$ (see Richardson et al. (2005) and Hou, Xue, and Zhang (2015)). |
| *PercentAccruals* (A) | Operating accruals (as defined above) scaled by the absolute value of net income (ni) from the fiscal year-end in calendar year $t − 1$ (see Hafzalla, Lundholm, and Van Winkle (2011)). |
| *AbnInvestment* (A) | Log of the ratio of capital expenditures (capx) to sales (sale) from the fiscal year-end in calendar year $t − 1$ minus the log of the average of that ratio taken over the prior three fiscal year-ends (see Titman, Wei, and Xie (2004)). |
| *InvestmentGrowth* (A) | Log of the gross percent change in capital expenditures (capx) from the fiscal year-end in calendar year $t − 2$ to the fiscal year-end in year $t − 1$ (see Xing (2008)). |

(*Continued*)

**Table CII**—*Continued*

| Variable Name | Variable Definition |
|---|---|
| *PPEChange* (A) | The ratio of the sum of the change in gross property, plant, and equipment (ppegt) and the change in inventories (invt) to total assets (at), where the changes are calculated from the fiscal year-end in calendar year $t-2$ to the fiscal year-end in calendar year $t-1$ and total assets is taken from the fiscal year-end in calendar year $t-2$ (see Lyandres, Sun, and Zhang (2008)). |
| *AssetGrowth* (A) | Log of the gross percent change in total assets (at) from the fiscal year-end in calendar year $t-2$ to the fiscal year-end in year $t-1$ (see Cooper, Gulen, and Schill (2008)). |

| Panel E: Earnings Surprise Variables | |
|---|---|
| *EarningsAnnounce-mentReturn* (MR) | The sum of a stock's return (ret) net of the market return from two days prior to the most recent earnings announcement date (rdq) to one day after. The variable is set to missing if the announcement date is more than six months after the earnings date (see Chan, Jegadeesh, and Lakonishok (1996)). |
| *StandardizedUn-expectedEarnings* (MR) | The change in quarterly earnings per share (epspxq) from four quarters ago to the value announced at the most recent earnings announcement date (rdq) scaled by the standard deviation of this change over the prior eight quarters. The variable is set to missing if the earnings announcement date is more than six months after the earnings date or if the standard deviation is calculated from fewer than six observations (see Foster, Olsen, and Shevlin (1984)). |

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## Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

**Appendix S1**: Internet Appendix.