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CAPM for estimating the cost of equity capital: Interpreting the empirical evidence ☆

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ABSTRACT

We argue that the empirical evidence against the capital asset pricing model (CAPM) based on stock returns does not invalidate its use for estimating the cost of capital for projects in making capital budgeting decisions. Because stocks are backed not only by projects in place, but also by the options to modify current projects and undertake new ones, the expected returns on stocks need not satisfy the CAPM even when expected returns of projects do. We provide empirical support for our arguments by developing a method for estimating firms' project CAPM betas and project returns. Our findings justify the continued use of the CAPM by firms in spite of the mounting evidence against it based on the cross section of stock returns.

1. Introduction

The Sharpe (1964) and Lintner (1965) capital asset pricing model (CAPM) is the workhorse of finance for estimating the cost of capital for project selection. Whatever the criticism in the academic literature, it continues to be the preferred model in managerial finance courses, and managers continue to use it. Welch (2008) finds that about 75.0% of finance professors recommend using the CAPM to estimate the cost of capital for capital budgeting. A survey of chief financial officers by Graham and Harvey (2001) indicates that 73.5% of the respondents use the CAPM.

The primary empirical challenge to the CAPM comes from several well-documented anomalies. A variety of

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managed portfolios constructed using various firm characteristics earn very different returns on average from those predicted by the CAPM.[3] Fama and French (1993) conjecture that two additional risk factors beyond the stock market factor used in empirical implementations of the CAPM are necessary to fully characterize economy-wide pervasive risk in stocks. Their three-factor model has received wide attention and has become the standard model for computing risk-adjusted returns in the empirical finance literature.

Almost all the proven anomalies apply to stock returns. Should that be a reason to refrain from using the CAPM to calculate the cost of capital for a project? We review the literature and provide new empirical evidence to argue that little direct evidence exists against using the CAPM to estimate a project's cost of capital. The particular model we consider is the Ross (1976) single-factor linear beta pricing model based on the stock index portfolio. We refer to this as the CAPM for convenience, following convention.

Most firms have the option to undertake, reject, or defer a new project, as well as the option to modify or terminate a current project. Therefore, we can look at a firm as a collection of current and future projects and complex options on those projects. McDonald and Siegel (1985) observe that managers should optimally exercise these real options to maximize a firm's total value. The resulting firm value consists of both the net present values of the projects and the value of associated real options, which is determined by how the firm expects to exercise those options. Berk, Green, and Naik (1999) build on this insight to develop a model in which the expected returns on all projects satisfy the CAPM, but the expected returns on the firm's stock do not. While the CAPM assigns the right expected returns to the primitive assets (projects), it in general assigns the wrong expected returns to options on those primitive assets. Gomes, Kogan, and Zhang (2003), Carlson, Fisher, and Giammarino (2004), and Cooper (2006) provide several additional insights in building on the Berk, Green, and Naik (1999) framework.[4]

We bring out the general intuition behind the failure of the CAPM in pricing options on primitive assets. This intuition comes from Dybvig and Ingersoll (1982) and Hansen and Richard (1987) in which a given stochastic discount factor, like the one corresponding to the CAPM, while assigning the right prices to a subset of assets, could assign the wrong prices to other assets. We first illustrate this intuition in a factor pricing example similar to that in Connor (1984). We then illustrate the impact of options in a numerical example that can be interpreted using the conditional CAPM of Jagannathan and Wang (1996). An econometrician using standard time series methods could conclude that the CAPM does not hold for firms with real options, even when the returns on such firms satisfy the CAPM in a conditional sense. When the sensitivity of firms' stock returns to economywide risk factors changes in nonlinear ways because of the presence of such real options, even when returns on individual primitive projects satisfy the CAPM, it could be necessary to use excess returns on certain managed portfolios [like the Fama and French (1993) SMB and HML factors] as additional risk factors to explain the cross section of stock returns. If that is the case, it would be justifiable to use the CAPM for estimating the cost of capital for projects, even if the CAPM cannot explain the cross section of average returns on various managed portfolios.

In general, both the equity risk premium and the equity beta of a firm are complex functions of the firm's project beta and real option characteristics. If we project them on a set of variables capturing the features of real options using linear regressions, the residual risk premium and the residual beta are option-adjusted and more closely resemble the underlying project risk premium and project beta. Consequently, the CAPM could work well on the option-adjusted risk premium and beta.[5]

We first provide support for the option-adjustment procedure and the CAPM with respect to the option-adjusted return and beta. We simulate a large cross section of all-equity-financed firms, each as a portfolio of a primitive asset (project) and a call option on the asset. While the CAPM works for the asset, in the presence of the option, it does not work for the firm as a whole. A cross-sectional regression of the firm risk premium on the firm beta produces a large intercept term, a very small slope coefficient, and an R-square close to zero, just as found in data. Once we option-adjust the firm's beta by making it orthogonal to a set of real option proxies (option moneyness, firm book-to-market ratio, and asset idiosyncratic volatility), however, the option-adjusted beta matches the underlying project beta very well and explains a large portion of the cross-sectional variation in option-adjusted firm risk premium.

We also provide empirical evidence supporting the use of the CAPM for calculating the cost of capital of a project for a full sample of stocks in the US from 1970 through 2008. Although real options are not directly observable, we proxy them using three empirical variables. The first

[3] Notable among the anomalies that challenge the validity of the CAPM are the findings that average returns on stocks are related to firm size (Banz, 1981), the earnings-to-price ratio (Basu, 1983), the book-to-market value of equity (Rosenberg, Reid, and Lanstein, 1985), the cash flow-to-price ratio, sales growth (Lakonishok, Shleifer, and Vishny, 1994), past returns (DeBondt and Thaler, 1985; Jegadeesh and Titman, 1993), and past earnings announcement surprise (Ball and Brown, 1968). Many other studies confirm similar patterns in different data sets, including in international markets.

[4] In related work, Bernardo, Chowdhry, and Goyal (2007) highlight the importance of separating the growth options from equity beta. Jagannathan and Wang (1996) argue that because of the nature of the real options vested with firms, the systematic risk of firms varies depending on economic conditions, and the stock returns of such firms exhibit option-like behavior.

[5] Jagannathan and Meier (2002) discuss another reason that the CAPM could be useful for capital budgeting. They argue that organizational capital could be in limited supply in firms with talented managers who generate positive net present value (NPV) projects. Such firms choose to implement only those projects with sufficiently large NPVs, as if they use a high hurdle rate by adding a large hurdle premium to their CAPM-based weighted average cost of capital. Jagannathan, Meier, and Tarhan (2011) find that, while managers do use a significant hurdle premium, the CAPM-based cost of capital is also an important determinant of the hurdle rate they use for making capital budgeting decisions.

variable is the firm's book-to-market ratio (*BM*), a common proxy for growth options in the finance literature [see Smith and Watts (1992) among others]. Berk, Green, and Naik (1999) explicitly links *BM* to growth options. The second is the idiosyncratic volatility (*Ivol*). Cao, Simin, and Zhao (2008) and Bekaert, Hodrick, and Zhang (2010) establish a theoretical link between the growth options available to managers and the idiosyncratic risk of equity. The third is the firm's return on asset (*ROA*). Recently, Chen, Novy-Marx, and Zhang (2010) argue that *ROA* is a good empirical proxy for the marginal product of capital, which is related to the marginal expansion option as in the real option model of Abel, Dixit, Eberly, and Pindyck (1996).

We examine the performance of the CAPM for project cost of capital calculation using a two-stage cross-sectional regression. In the first stage, we regress both the stock excess return and the stock beta on the three real option proxies. The real options proxies are measured in excess of these measures of the market, and the regression has no intercept terms; such procedures ensure that the CAPM holds for the market exactly. The residual excess returns and betas are option-adjusted. In the second stage, we regress the option-adjusted excess return on the option-adjusted beta. While the stock beta is not significant in explaining the cross-sectional variation in average excess returns, the option-adjusted beta is very significant in explaining the cross-sectional variation in average option-adjusted excess returns. We correct the errors-in-variables problem in our cross-sectional regression that arises from estimation errors associated with the rolling-window betas (Jagannathan, Kim, and Skoulakis, 2010). After this correction, we find the regression slope coefficient on the option-adjusted beta to be closer to the actual market risk premium and the regression intercept to be much closer to zero, consistent with the prediction of the CAPM. The option-adjusted beta is related to but not exactly equal to the beta on the firm's asset-in-place. This is because a firm's beta is in general a complicated function of the asset-in-place beta and the beta of embedded options. A linear regression procedure does not do a perfect job in isolating the asset-in-place beta.

Finally, we investigate the impact of real option adjustment on several well-known cross-sectional expected return anomalies. We find that real option adjustment alleviates or even drives out several anomalies related to long-term stock price mean reversion. These anomalies include the asset growth anomaly of Cooper, Gulen, and Schill (2008), the investment-related anomaly of Anderson and Garcia-Feijoo (2006), Xing (2008), and Chen, Novy-Marx, and Zhang (2010), and the long-term return reversal of DeBondt and Thaler (1985). The real option adjustment, however, has little impact on anomalies that are related to short-term return continuation such as price momentum (Jegadeesh and Titman, 1993) and earnings momentum (Chan, Jegadeesh, and Lakonishok, 1996). To the extent that such short-term price continuation typically does not persist beyond a few quarters and requires frequent portfolio rebalancing, it is probably less relevant for the cost of capital calculation for a typical project whose life usually extends beyond five years.

When we confine the analysis to a subsample of stocks after excluding stocks whose betas are likely to be measured with large errors, support for use of the CAPM beta in project cost of capital calculation becomes even stronger. For instance, the slope coefficient in the cross-sectional regressions is almost the same as the historical average excess return on the stock market index, and the intercept term is insignificantly different from zero.

Determination of the cost of capital has been an important focus in finance. Fama and French make a convincing case that the CAPM fails to describe the cross section of stock returns (Fama and French, 1992, 1996, 1997, 1999, 2004, and 2006).[6] Most of the research in the asset pricing literature focuses on understanding the determinants of expected returns on stocks.[7] Our primary interest, however, is in evaluating the empirical evidence against the use of the CAPM for project cost of capital calculations in making capital budgeting decisions.

We illustrate the impact of real options through two examples in Section 2 and also provide a more detailed review of the related literature. Section 3 describes a simple regression procedure to alleviate the effect of real options and a simulation example. Section 4 demonstrates the effectiveness of option-adjusted beta and presents evidence that supports use of the CAPM in project cost of capital estimation using empirical analysis. Section 5 concludes.

2. Examples

Dybvig and Ingersoll (1982) and Hansen and Richard (1987) point out that a given stochastic discount factor (SDF), like the one corresponding to the CAPM, while assigning the right prices to a subset of assets, could assign the wrong prices to other assets. Treynor and Mazuy (1966), Henriksson and Merton (1981), Merton (1981), Dybvig and Ross (1985), Jagannathan and Korajczyk (1986), and Glosten and Jagannathan (1994) make related observations that, in an economy in which the CAPM holds for stock returns, the returns on managed portfolios that have option-like features might not satisfy the CAPM. We use two examples to illustrate the intuition behind those observations, i.e., why the CAPM might price the expected returns on primitive projects but not those on options.

We first explain this intuition in a factor pricing example similar to that in Connor (1984). In this example, the CAPM could hold conditionally as well as unconditionally for a subset of assets but need not hold either conditionally or unconditionally for other assets. In the second numerical example, we show that this intuition

[6] Among many other related works, Ferson and Locke (1998) find that the great majority of the error in estimating the cost of equity capital using the CAPM is due to the risk premium estimate; Pastor and Stambaugh (1999) show that the cost of equity estimation can be improved in a Bayesian framework; Ang and Liu (2004) discuss a general approach for discounting cash flows with time-varying expected returns.

[7] We refer readers interested in the broader asset pricing literature to the excellent surveys by Campbell (2003), Duffie (2003), Ferson (2003), and Mehra and Prescott (2003).

can also be made clear using the observations in Jagannathan and Wang (1996), Gomes, Kogan, and Zhang (2003), and Zhang (2005), who show that the CAPM might not hold unconditionally even when it holds in a conditional sense.

2.1. The CAPM in a factor economy of Connor (1984)

Following Connor (1984), who derives an equilibrium version of the Ross (1976) Arbitrage Pricing Theory, consider an economy with K economywide pervasive factors, where the representative investor's marginal utility for end-of-period wealth is a function of only those pervasive factors. In such an economy, Connor (1984) shows that there is a unique SDF, that is, some nonlinear function of the pervasive factors that assigns the right prices to all assets. We consider the special case where $K=1$; i.e., there is only one pervasive factor, which is the return on aggregate wealth portfolio (or the market portfolio).

Now, following Connor (1984), consider a subset of assets (denoted as projects) whose returns have the linear factor structure

$$r_i = a_i + b_i r_m + \varepsilon_i, \tag{1}$$

where r_m is the market return (all returns in this subsection are gross returns) and $\mathrm{E}[\varepsilon_i|r_m]=0$. As a result, the slope coefficient b_i (which we call the CAPM beta for convenience) can be computed by regressing r_i on r_m. Let M denote the unique SDF that prices all assets correctly. Recall that $M=f(r_m)$, i.e., M is some nonlinear function of only r_m. The function f is linear only under special circumstances [such as when investors have quadratic utility as shown in Dybvig and Ingersoll (1982)].

The economy could also include options whose returns do not have the linear factor structure. Nevertheless, we can still regress the option return on the market return and write

$$r_o = a_o + b_o r_m + \varepsilon_o, \tag{2}$$

where ε_o satisfies $\mathrm{E}[\varepsilon_o r_m]=0$ by definition of "regression," but $\mathrm{E}[\varepsilon_o|r_m]$ is strictly different from zero. In that case, without loss of generality, it should be possible to choose the option in such a way (i.e., such an option exists because we are in a complete market economy) that $\mathrm{E}[\varepsilon_o f(r_m)]=\mathrm{E}[\varepsilon_o M]\neq 0$.

Because M is a valid pricing kernel, we have

$$\mathrm{E}[M r_m]=1 \tag{3}$$

and

$$\mathrm{E}[M r_i]=\mathrm{E}[M(a_i+b_i r_m+\varepsilon_i)]=1. \tag{4}$$

The assumption $\mathrm{E}[\varepsilon_i|r_m]=0$ implies $\mathrm{E}[f(r_m)\varepsilon_i]=0$ or $\mathrm{E}[M\varepsilon_i]=0$. Therefore we have

$$a_i\mathrm{E}[M]+b_i=1. \tag{5}$$

If a risk-free asset exists, then the risk-free rate satisfies

$$r_f=\frac{1}{\mathrm{E}[M]} \tag{6}$$

Substituting this expression for r_f into $a_i\mathrm{E}[M]+b_i=1$ gives $a_i=r_f-r_f b_i$.

By substituting this expression for a_i into the expression for expected returns on any project i whose return has a linear factor structure, we get

$$\mathrm{E}[r_i]=a_i+b_i\mathrm{E}[r_m] \tag{7}$$

and

$$\mathrm{E}[r_i]=r_f+b_i\mathrm{E}[r_m-r_f], \tag{8}$$

which gives the CAPM linear-beta-pricing relation for all assets, i, with returns that have a strict linear factor structure.

The expected return on the option, however, does not satisfy this CAPM relation. This is because, when we price the option return using M, we have

$$\mathrm{E}[M r_o]=\mathrm{E}[M(a_o+b_o r_m+\varepsilon_o)]=1. \tag{9}$$

Because $\mathrm{E}[M\varepsilon_o]=\mathrm{E}[f(r_m)\varepsilon_o]\neq 0$, we have

$$a_o\mathrm{E}[M]+b_o=-\mathrm{E}(M\varepsilon_o)+1, \tag{10}$$

$$a_o=r_f-r_f b_o-r_f\mathrm{E}(M\varepsilon_o), \tag{11}$$

and

$$\mathrm{E}[r_o]=-r_f\mathrm{E}(M\varepsilon_o)+r_f+b_o\mathrm{E}[r_m-r_f]. \tag{12}$$

Thus the CAPM relation does not hold for the option expected return.

However, a CAPM-like single beta relation does hold for all assets, including options that do not have linear factor structure when r_m is replaced by the return on the asset whose payoff is identical to that of M (such asset exists when the market is complete). However, the CAPM single beta relation (where beta is the regression slope coefficient of the return on the asset on the return on the market portfolio) holds only for those assets that have a linear factor structure.[8]

2.2. A numerical example and the conditional CAPM

Now we present a numerical example in which the CAPM correctly prices all primitive projects but not the stock expected returns, and asset pricing anomalies such as size and book-to-market effects arise. The example is consistent with several empirical regularities: (1) value stocks have higher expected returns than the market and have positive CAPM alphas; (2) growth stocks have lower expected returns than the market and have negative CAPM alphas; (3) value stocks have lower CAPM betas than growth stocks; (4) the equity risk premium is countercyclical; (5) value stocks are riskier than growth stocks when the expected risk premium is high; and (6) size and BM can describe cross-sectional variation in expected returns on stocks. The intuition behind these

[8] To see this more clearly, let M^* denote the linear projection of M on the set of returns that have a linear factor structure and let $P(M^*)$ denote the price of M^*. Then $M^*/P(M^*)-r_f=K(r_m-r_f)$ where K is a constant, because $M^*/P(M^*)$ is the minimum second moment return on the mean variance return frontier generated by the returns that have a linear factor structure (see Hansen and Richard, 1987).

patterns can be understood in the context of the conditional CAPM.

This example and the first one illustrate that when a firm is endowed with real options, the CAPM does not explain its equity expected return, and anomalies such as size and *BM* effects can arise. The CAPM could still hold, however, for the primitive projects and can be used to compute the costs of capital for projects.

2.2.1. The economy

For purpose of illustration, we consider an economy with a market risk premium of 5% per year, an annual risk-free rate of 5%, and a flat yield curve. There are three possible states at the end of the year: Up (probability: 25%), Mid (probability: 50%), and Down (probability: 25%). The returns on the market portfolio in these three states are 40.4%, 8.0%, and −16.3%, respectively, translating to an expected return of 10.0% for the market portfolio.

A firm in this economy consists of multiple projects and one option. All projects are identical with an initial cost of \$1.00, which can be viewed as the book value. Once undertaken, each project pays out an expected perpetual annual cash flow of \$0.20. By assumption, the CAPM prices these projects, which all have a CAPM beta of one, with an appropriate discount rate of 10% ($5\%+1\times5\%=10\%$ as predicted by the CAPM). The market value of each project is therefore $0.20/10\%=\$2.00$.

The option can be one of two types: a value option (VO) or a growth option (GO). The state-contingent payoffs of the value option are \$0.949 (Up), \$0.949 (Mid), and 0.456 (Down), while the payoffs of the growth option are \$1.808 (Up), \$1.095 (Mid), and 1.095 (Down).

2.2.2. Prices and expected returns

We assume no arbitrage opportunities exist, i.e., all SDFs that assign the right prices are strictly positive. Consider one such valid SDF, $M=[0.7313,\ 0.8164,\ 1.4454]$ across Up, Mid, and Down states. It can be verified that $E[M(1+R)]=1$ for the risk-free rate and the market return, meaning the SDF can price the risk-free asset and the market portfolio. With the SDF, we can price the two options using $E[M\times payoff]$. The results are summarized in Panel A of Table 1.

Given the prices of these two options, we can compute their annual returns and expected returns. With the help of returns on any of the two options, the market is now complete, and it can be verified that M is the unique SDF that prices all the assets in this economy. Because there are three states, the option payoffs cannot be replicated by trading only the market portfolio and the risk-free asset. The option return, therefore, does not satisfy the factor structure assumption $E[\varepsilon_o|r_m]=0$ so the CAPM relation does not apply to its expected return. This can be seen by computing options' covariances with the market and their CAPM betas. Although value option has a higher expected return (13.8%) than the market while the growth option has a lower expected return (8.5%) than the market, the growth option has a higher CAPM beta.

Because of the higher CAPM beta, the CAPM predicts a higher expected return on the growth option (10.7%) than on the value option (10.5%). In other words, the CAPM, although perfectly explaining the expected returns on primitive projects in the economy, fails to explain the expected returns on these two options. As a result, the value option seems to outperform the market (it carries a positive CAPM alpha of $13.8-10.5\%=3.3\%$) while the

Table 1
Numerical example.

Panel A: Parameters of the economy

State	Probability	State price	Riskfree rate	Market\return	Value option payoff	Value option return	Growth option payoff	Growth option return
Up	0.25	0.7313	5.0%	40.4%	\$0.949	30.7%	\$1.808	54.0%
Mid	0.50	0.8164	5.0%	8.0%	\$0.949	30.7%	\$1.095	−6.6%
Down	0.25	1.4454	5.0%	−16.3%	\$0.456	−37.1%	\$1.095	−6.6%
Price					\$0.726		\$1.173	
ER			5.0%	10.0%		13.8%		8.5%
CAPM beta			0.00	1.00		1.10		1.14
CAPM ER				10.0%		10.5%		10.7%

Panel B: Value and growth option in the expanded two-period binomial tree

Value option			Growth option		
$T=0$	$T=$Six months	$T=$One year	$T=0$	$T=$Six months	$T=$One year
		\$0.949			\$1.808
	\$0.926			\$1.390	
\$0.726		\$0.949	\$1.173		\$1.095
	\$0.614			\$1.069	
		\$0.456			\$1.095

Panel C: Value and growth option in different states

State	Market ER (%)	Value option beta	Value option ER (%)	Growth option beta	Growth option ER (%)
U	3.5	0.00	2.5	1.90	4.4
D	6.5	2.97	14.4	0.00	2.5

growth option seems to under-perform the market (it carries a negative CAPM alpha of $8.5-10.7\%=-2.2\%$).

2.2.3. The conditional CAPM

The intuition behind these results can be made clearer using the conditional CAPM of Jagannathan and Wang (1996) or, more broadly, the results in Hansen and Richard (1987). The conditional CAPM interpretation adds economic insights on why the value option earns a higher expected return than the growth option.

When we add an intermediate time period to the example, the one-period trinomial tree is expanded to be a two-period binomial tree. The two states (U and D) on each node are associated with equal probability. The state-contingent payoffs of an investment in the market portfolio (assuming an initial investment of \$1) are \$1.200 (U) and \$0.900 (D) at the intermediate time period (T=six month); and payoffs are \$1.404 (UU), 1.080 (UD, DU), and 0.837 (DD) at the second period (T=one year). The risk-free rate in each six-month period is $1.05^{0.5}-1=2.47\%$.

The immediate consequence of adding the intermediate state is that the market is now dynamically complete with only two assets, the market portfolio and the risk-free asset, because the option payoff can be replicated by trading these two assets dynamically. Both the value option and the growth option can be priced (as in Panel B of Table 1) using the standard no-arbitrage replication argument, which justifies the SDF given in Section 2.2.2 [see Rubinstein (1976) among others].

Given the payoffs (and the implied returns) of both the market and the options, we can compute the values on both nodes U and D for the period from six months to one year, as in Panel C of Table 1. The expected return on the market going forward is higher following a negative market return in state D, consistent with the fact that the risk premium is countercyclical. In addition, the CAPM works for both options conditionally (on each node). This is not surprising, as the option can be replicated by both the market and the bond, and the CAPM prices the expected returns on both assets (see Dybvig and Ross, 1985).

The value option has a higher expected return unconditionally because it has a higher beta in state D, precisely when the market risk premium is high. This is highlighted by Jagannathan and Korajczyk (1986) and is the key insight of the conditional CAPM of Jagannathan and Wang (1996).

Are value stocks riskier when the risk premium going forward is high? Some empirical evidence in the literature suggests the answer is yes. For example, Petkova and Zhang (2005) find that value betas tend to covary positively and growth betas tend to covary negatively with the expected market risk premium, which offers at least a partial explanation for the value premium.[9] Why are value stocks more risky when the expected risk premium is high? Zhang (2005) provides an elegant explanation within the framework of the neoclassical theory of investment. It is more costly for value firms to downsize their capital assets because they are typically burdened with more unproductive capital. As a result, value stocks' returns covary more with economic downturns when the expected risk premium is high.[10]

2.2.4. Stock characteristics

Despite the failure of the CAPM in pricing options, the book-to-market ratio and the size of the firm serve as two sufficient statistics for describing the expected returns of all firms in the economy. To see this, note that all firms in the economy have two components: (1) the assets-in-place component, which includes I_i projects, and (2) the option component (O_i=VO or GO). The market value or size of each firm is $V_i=2I_i+O_i$. The expected return of the firm is a weighted average of expected returns on these two components: $ER_i=2I_i/V_i\times 10\%+O_i/V_i\times ER_O$. It can easily be verified that, whether a firm is endowed with the value option or the growth option, its expected return can be expressed as $20\%\times BM+10\%/Size$. Therefore the expected return increases with BM and declines with $Size$. In addition, BM and $Size$ explain the expected returns on all firms.

Firms with the value option resemble value stocks. These firms have more assets-in-place, and because the value option is cheaper, value stocks are associated with higher BM. Because the value option has a higher expected return and positive CAPM alpha, so do the value stocks. Firms with the growth option resemble growth stocks. Unlike value stocks, growth stocks have lower BM values, lower expected returns, and negative CAPM alphas.

Why do characteristics such as BM and size describe cross-sectional return variations? The key intuition follows from Berk (1995). Given expectations about future payoffs, market value must be correlated with systematic risk across stocks. In our numerical example, BM summarizes the firm's risk relative to the scale of its asset base, and size describes the relative importance of assets-in-place and the option.

Other work combines this intuition with key insights from the real options literature pioneered by McDonald and Siegel (1985) in linking firm-specific investment patterns, valuation, and expected returns. A seminal paper

[9] Other recent studies on the conditional CAPM include Wang (2003), Ang and Chen (2007), and Gulen, Xing, and Zhang (2011). Similar evidence is provided in the context of the consumption CAPM by Lettau and Ludvigson (2001), Santos and Veronesi (2006), and Lustig and Van Nieuwerburgh (2005).

[10] Lewellen and Nagel (2006), however, argue that the variation in betas and the equity premium would have to be implausibly great for the conditional CAPM to explain the size of the value premium. Lewellen and Nagel (2006) use high-frequency returns in their empirical analysis. Chan, Hameed, and Lau (2003) demonstrate that price and return could be driven in part by factors unrelated to fundamental cash flow risk. Such factors, together with liquidity events, could contaminate the estimation of beta at higher frequencies (see Pastor and Stambaugh, 2003). Bali, Cakici, and Tang (2009) and Bauer, Cosemans, Frehen, and Schotman (2009) improve the cross-sectional performance of the conditional CAPM by using more efficient estimation techniques. Kumar, Sarescu, Boehme, and Danielsen (2008) and Adrian and Franzoni (2008) demonstrate that once the estimation risk or parameter uncertainty associated with beta and risk premium are accounted for, the conditional CAPM has significantly more cross-sectional explanatory power and could explain the value premium after all.

by Berk, Green, and Naik (1999) studies the implications of the optimal exercise of real investment options. In their model, investment opportunities with low systematic risk are attractive to the firm. Making such investments increases firm value and reduces the average risk of the firm. Consequently, the expected return of the firm is dynamically linked to price-based characteristics such as *BM* and *Size*. Gomes, Kogan, and Zhang (2003) show that these results continue to hold in a general equilibrium setting as well. *Size* and *BM*, correlated with true conditional betas in their model, help to explain stock returns in the cross section, especially when true betas are measured with error.

Carlson, Fisher, and Giammarino (2004) model the optimal dynamic investment behavior of monopolistic firms facing stochastic product market conditions. Their approach is similar in spirit to Berk, Green, and Naik (1999), except that they also introduce operating leverage, reversible real options, fixed adjustment costs, and finite growth opportunities. They show that the *BM* effect can arise even if there is no cross-sectional dispersion in project risk, as *BM* summarizes market demand conditions relative to invested capital.

Zhang (2005) demonstrates in an industry equilibrium model that the firm's optimal investments, together with asymmetry in capital adjustment costs and the counter cyclical price of risk, can generate the *BM* effect. This is because value firms have difficulty disinvesting, making them more risky in bad times when the market risk premium is high. Cooper (2006) develops a dynamic model that allows the *BM* to be informative of the deviation of a firm's actual capital stock from its target. As a firm becomes distressed, book value remains constant, but market value falls, resulting in higher *BM*. Going forward, its extra installed capacity allows it to expand production easily without new investment, making its payoff more sensitive to aggregate shocks and its equity more risky. Empirically, Anderson and Garcia-Feijoo (2006) and Xing (2008) together provide supporting evidence that the investment dynamics of a firm drive the *BM* effect. More recently, Liu, Whited, and Zhang (2009) show that the dispersion in investment-to-capital between value and growth firms is the main driving force of the *BM* effect.

3. The CAPM and the real option adjustment

More generally, both the equity risk premium and beta are functions of the project beta and other variables capturing real option effects. Assume that these functions can be linearized around the values of the market portfolio with small errors:

$$\mu_i = f(\mu_i^p, OP_i) = f(\mu_M^p, OP_M) + f_1(\mu_i^p - \mu_M^p) + f_2'(OP_i - OP_M) + \varepsilon_i \tag{13}$$

and

$$\beta_i = g(\beta_i^p, OP_i) = g(\beta_M^p, OP_M) + g_1(\beta_i^p - \beta_M^p) + g_2'(OP_i - OP_M) + \eta_i, \tag{14}$$

where μ_i and β_i are the equity risk premium and the equity CAPM beta on stock *i*; μ_i^p and β_i^p denote the project risk premium and the project CAPM beta on stock *i*; and OP_i represents the vector of variables that captures the effect of real options. Subscript *M* denotes the market portfolio. By construction, $f(\mu_M^p, OP_M) = \mu_M$ and $g(\beta_M^p, OP_M) = \beta_M = 1$. While the CAPM could fail to explain the equity risk premium ($\mu_i \neq \beta_i \mu_M$) because of the presence of real options, it could work for projects themselves ($\mu_i^p = \beta_i^p \mu_M$). The linearization thus suggests that if we remove the real option effects (terms involving OP_i) from μ_i and β_i, the residual (or real option-adjusted) equity risk premium and beta should generally satisfy a linear relation (subject to linearization errors).

Cross-sectional regressions (without the constant) can be used to remove the effect of OP_i from μ_i and β_i

$$\mu_i = a'(OP_i - OP_M) + \mu_i^{OA}. \tag{15}$$

$$\beta_i = b'(OP_i - OP_M) + \beta_i^{OA}. \tag{16}$$

The residuals, μ_i^{OA} and β_i^{OA}, can be viewed as the option-adjusted equity risk premium and the equity CAPM beta on stock *i*, and in that case we should expect $\mu_i^{OA} \propto \beta_i^{OA}$.

Because the market index portfolio is a value-weighted average of all stocks, if we take the cross-sectional (value-weighted) average of the option-adjusted equity risk premium and beta across all stocks, we have

$$\mu_M = \overline{\mu_i} = \overline{\mu_i^{OA}} \tag{17}$$

and

$$\beta_M = \overline{\beta_i} = \overline{\beta_i^{OA}}. \tag{18}$$

Because $\beta_M = 1$ by construction, $\overline{\mu_i^{OA}} = \overline{\beta_i^{OA}} \times \mu_M$, which in turn implies

$$\mu_i^{OA} = \beta_i^{OA} \mu_M. \tag{19}$$

This constitutes the main testable hypothesis of our work: the option-adjusted CAPM beta explains the cross section of option-adjusted equity returns. We test this hypothesis first using simulation analysis.

3.1. Simulation evidence

In a simulation exercise to evaluate the effect of real options on expected firm stock returns and the performance of the CAPM, we consider a large cross section of all-equity-financed firms. Each firm consists of one primitive asset (project) and a call option on the asset. The assets differ in their CAPM beta (β_i^p) and idiosyncratic volatility ($Ivol_i$). For simplicity, we assume that all assets are associated with a book value of \$1 and a market value of \$1 and that the expected return on the primitive asset satisfies the CAPM.

All call options expire in one year and differ in their moneyness (k_i). We assume that the call option can be priced using the standard Black and Scholes (1973) model. The cross-sectional variation in the call prices is therefore driven by three parameters: k_i, $Ivol_i$, and β_i^p. The last two parameters jointly determine the volatility of the asset ($\sigma_i^2 = (\beta_i^p \sigma_M)^2 + Ivol_i^2$). The call price then determines w_i,

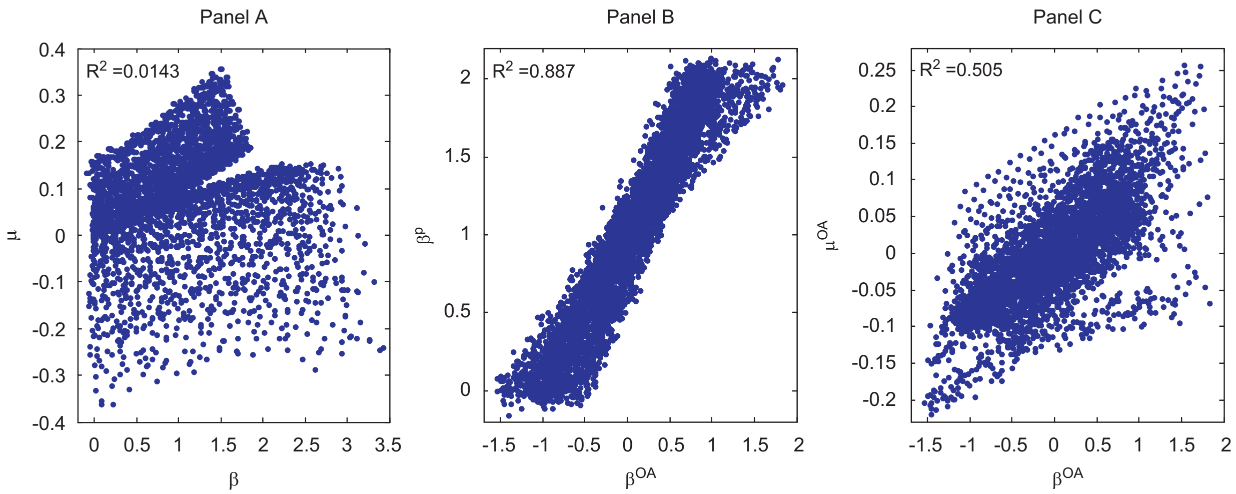

Fig. 1. Option-adjusted betas and the capital asset pricing model (CAPM): simulation evidence. We generate a large cross section of firms. Each firm is a portfolio of a primitive asset (project) and a call option on it. The call options expire in one year. We assume a market risk premium (μ_M) of 8.00% and a market risk-free rate of 1.00%. We also assume a market volatility of 0.20 (on the log market return). We vary option moneyness (k_i) from 0.75 to 1.25 in increments of 0.05. We vary asset idiosyncratic volatility ($Ivol_i$) from 0.10 to 0.70 in increments of 0.10. We vary the primitive project beta (β_i^p) from 0 to 2 in increments of 0.10. For each firm with a short position in a call option, we also generate two otherwise identical firms, each with a long position in the same option. For each firm, we compute the risk premium (μ_i) and the CAPM beta (β_i) of the stock numerically using Monte Carlo simulations. The option-adjusted beta (β_i^{OA}) is the residual of regressing the firm CAPM beta on the option proxies [BM_i, k_i, $Ivol_i$] in a cross-sectional regression with no constant. The option-adjusted firm risk premium (μ_i^{OA}) is the residual of regressing the firm risk premium (μ_i) on the option proxies in the cross section with no constant. Finally, we add a measurement error to the CAPM beta, drawn from a normal distribution of zero mean and a variance of 0.01. Panel A plots the firm risk premium against firm CAPM beta. Panel B plots the firm CAPM beta against option-adjusted beta. Panel C plots the option-adjusted risk premium against option-adjusted beta.

the weight of the option value as a percentage of the total value of the firm i. More precisely, $w_i = I_iO_i/(1+I_iO_i)$, where I_i is equal to 1 (-1) if firm i is taking a long (short) position in the call option, and O_i denotes the option value. In this simple economy, the book-to-market ratio of the firm perfectly reveals its option weight ($BM_i = (1/(1+I_iO_i)) = 1-w_i$). The expected return on the firm does not satisfy the CAPM because there is a call option. Overall, the risk premium on firm i (μ_i) is a value-weighted average of the risk premium on the project (μ_i^p) and the option (μ_i^O):

$$\mu_i = (1-w_i)\mu_i^p + w_i\mu_i^O = (1-w_i)\beta_i^p\mu_M + w_i\mu_i^O. \tag{20}$$

We generate the cross section of firms by choosing the parameter values as follows (on an annual basis): a market risk premium (μ_M) of 8.00%; a market risk-free rate of 1.00%; a market volatility of 0.20 (on the log market return); values for k_i from 0.75 to 1.25 in increments of 0.05 at a time; values for $Ivol_i$ from 0.10 to 0.70 in increments of 0.10 at a time; and values of the primitive project beta (β_i^p) from 0 to 2 in increments of 0.10 at a time. Finally, for each firm with a short position in a call option, we also generate two otherwise identical firms, each with a long position in the same option so options are in positive net supply overall.

For each firm we can compute the risk premium (μ_i) and the CAPM beta (β_i) of the stock numerically.[11] Finally, the CAPM beta is measured with errors, and the measurement error is drawn from a normal distribution of zero mean and a variance of 0.01.

As the CAPM cannot price the expected return on the option component, it is not able to price the expected return on the firm either. Panel A of Fig. 1 confirms this result. When we plot the firm's expected return versus its CAPM betas, we do not observe a significant positive relation as would be predicted by the CAPM. In fact, if we run a cross-sectional regression of firm expected return on firm CAPM betas, we confirm the well-documented failure of the CAPM to explain the cross-sectional variation in equity risk premium. First, the slope coefficient, which can be interpreted as the market risk premium, is only 2.04%, which is way below the assumed value of 8.00%. Second, when the risk premium estimate is biased toward zero, the intercept term is likely to be positive and significant. This is exactly what we find. The intercept term is 7.00% with a t-value of about 24.40. Finally, the regression R-square is lower than 2.00%.

As the CAPM holds on the primitive projects by construction in our simulation, the failure of the CAPM to predict firm returns should not invalidate its use for the purpose of project cost of capital calculation. Our main hypothesis posits that the CAPM should hold approximately

[11] Specifically, for each firm, we use Monte Carlo simulation to generate ten thousand possible project payoffs at the end of the year. For each project payoff, we compute the corresponding option payoff. The expected payoffs are computed as averages across all ten thousand paths. The covariance between the firm return and the market return and the beta can also be computed using these ten thousand realizations.

for the option-adjusted equity risk premium and beta, and we test that in our simulated sample.

The cross-sectional variation in real option effects in our example can be fully captured by three parameters: the book-to-market ratio (BM_i), the moneyness of the call option (k_i), and the idiosyncratic volatility ($Ivol_i$). Therefore, the option proxies (OP_i) in this example are a vector of cross-sectionally demeaned [BM_i, k_i, $Ivol_i$].

We remove the option effects from the firm CAPM beta by regressing it on the option proxies in a cross-sectional regression with no constant. The residual or the option-adjusted beta (β_i^{OA}) should therefore capture the project CAPM beta. We verify this in Panel B of Fig. 1. When plotted together, the project beta (β_i^p) lines up well with the option-adjusted beta (β_i^{OA}). When we regress β_i^p on β_i^{OA}, we get an R-square almost of 90.00% and a slope of 0.91. Despite the nonlinear nature of the option effect, a simple linear regression seems to be successful in removing option effects from the firm beta and recovering the project beta.

In addition, we regress the firm risk premium (μ_i) on the option proxies in the cross section with no constant to obtain the option-adjusted firm risk premium (μ_i^{OA}). The option-adjusted risk premium should capture the risk premium on the project. Our main hypothesis predicts that μ_i^{OA} will be equal to the product of the option-adjusted beta and the market risk premium, or $\mu_i^{OA} = \beta_i^{OA}\mu_M$. Panel C of Fig. 1 provides supporting evidence for the hypothesis. We find that μ_i^{OA} is clearly positively related to β_i^{OA}. When we regress μ_i^{OA} on β_i^{OA}, we find a slope coefficient of 8.10%, which is close to the assumed market risk premium of 8.00%. At the same time, the intercept term is -0.04%, not significantly different from zero. In other words, the CAPM performs better once the option effects are removed with a simple regression procedure. Finally, the R-square is also much higher at 50.5%. The R-square is not equal to one for a couple of reasons. First, linear approximation errors affect both μ_i^{OA} and β_i^{OA}. Second, beta is assumed to be measured with error.

4. The CAPM and project cost of capital: empirical analysis

For our empirical analysis, we conduct monthly Fama and MacBeth (1973) cross-sectional regressions at the individual stock level with the Newey and West (1987) correction using a lag of 36. Each month, we regress monthly stock excess return (over the risk-free rate) on betas and stock characteristics that are measured using the most recent return and accounting data available to investors.

4.1. Sample and variable definitions

We start with firms covered by the Center for Research in Security Prices (CRSP) with common shares outstanding over 1970–2008, with the exclusion of penny stocks (with prices lower than $5) and firms listed for less than three years. For each sample firm, the beta estimates are calculated as the slope coefficients of the CAPM regressions; and $Beta\_{MKT}$, $Beta\_{SMB}$, and $Beta\_{HML}$ are computed as the slope coefficients of the Fama and French three-factor regressions, both using the prior 60 months of return records from CRSP.[12]

Two return anomaly variables are constructed using the CRSP data: medium-term price momentum (*Momt*) as the cumulative monthly stock return of $[t-13,\ t-2]$, and long-term return reversal (*Lret*) as the cumulative monthly stock returns of $[t-60,\ t-13]$, prior to month t. Monthly idiosyncratic volatility (*Ivol*) in month t is computed following the procedure in Ang, Hodrick, Xing, and Zhang (2006).

Our CRSP sample is further intersected with Compustat data when accounting information is available. We require a minimum six-month gap in matching the accounting data of calendar year $t-1$ with monthly return data of calendar year t to ensure that the accounting information is available to market investors. We construct a number of variables using information available from Compustat files. *BE* is book value (in millions) as the sum of stockholders' equity, deferred tax, investment tax credits, and convertible debt, minus the liquidation value of preferred stocks (Fama and French, 1992, 1993). *BM* is the ratio of BE over firm market capitalization measured as of the most recent June. *ROA* is the ratio of quarterly earnings scaled by the asset in the prior quarter. The asset growth rate (*Ast_gw*) is calculated as the year-on-year percentage change in total assets (Cooper, Gulen, and Schill, 2008), and investment-to-capital ratio (*Inv*) is the annual change in gross property, plant, and equipment scaled by the lagged book value of assets (Chen, Novy-Marx, and Zhang, 2010). Earnings surprise (*Sue*) is computed using the difference in quarterly earnings in the $[t-3,\ t-6]$ window and the corresponding value announced four quarters ago scaled by the standard deviation of the corresponding earnings change over the previous eight quarters prior to return measurement in month t (Chan, Jegadeesh, and Lakonishok, 1996.) Table 2 defines all the variables.

We focus on *BM*, *Ivol*, and *ROA* as our empirical real option proxies. *BM* is a common proxy for growth options in the finance literature [see Smith and Watts (1992) among others.] The choice of *Ivol* is motivated by Cao, Simin, and Zhao (2008) and Bekaert, Hodrick, and Zhang (2010), which establish a theoretical link between growth options available to managers and the idiosyncratic risk of equity. Finally, Chen, Novy-Marx, and Zhang (2010) argue that *ROA* is a good empirical proxy for the marginal product of capital, which is related to the marginal expansion option as in the real option model of Abel, Dixit, Eberly, and Pindyck (1996). The choices of these

[12] Hoberg and Welch (2007) argue that investors could be slow in adjusting to recent changes in market risk, and they recommend the use of aged beta. For this reason, we also examine aged betas (the CAPM beta estimated using $[t-85,\ t-25]$ five-year rolling windows after skipping the most recent two years) and find them to produce similar results in the cross-sectional regressions.

Table 2
Variable definition.

Variable	Definition
Beta	Capital asset pricing model (CAPM) beta estimated using five-year monthly return data prior to return measurement in month t
Size	Market capitalization (in millions) measured on the last trading day of June
BE	Book value. If the data item of Compustat Data216 is not missing, then BE=Data216−Data10+Data35+Data79, otherwise BE=Data6−Data181−Data10+Data35+Data79
BM	Ratio of *BE* to *Size*
ROA	Ratio of quarterly earnings scaled by the one-quarter-lagged asset in the prior quarter
Ivol	Monthly idiosyncratic volatility in month $t-1$ computed following the procedure described in Ang, Hodrick, Xing, and Zhang (2006)
Momt	Cumulative monthly stock returns of $[t-13, t-2]$ prior to return measurement in month t
Sue	Earnings surprise computed using the difference in quarterly earnings in the $[t-3, t-6]$ window and the corresponding value announced four quarters ago scaled by the standard deviation of the corresponding earnings change over the previous eight quarters prior to return measurement in month t
Ast_gw	Growth rate of total asset value in the prior year computed following the procedure as described in Cooper, Gulen, and Schill (2008)
Inv	Investment-to-capital ratio as the annual change in sum of gross property, plant, and equipment and inventories scaled by lagged book assets as described in Chen, Novy-Marx, and Zhang (2010)
Lret	Cumulative monthly stock returns of $[t-60, t-13]$ prior to return measurement in month t
MKT, *SMB*, and *HML*	Fama and French three factors with *MKT* as the Center for Research in Security Prices (CRSP) value-weighted return on all stocks and *SMB* and *HML* as the size and value factors

Table 3
Correlation matrix.

Pearson correlations of capital asset pricing model (CAPM) beta, betas of Fama and French three factors ($Beta\_{MKT}$, $Beta\_{SMB}$, and $Beta\_{HML}$), other return anomaly variables (*Ast_gw*, *Inv*, *Lret*, *Momt*, and *Sue*) and real option variables (*BM*, *Ivol*, and *ROA*) are presented. See Table 2 for variable definitions. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

	Beta	$Beta\_{MKT}$	$Beta\_{SMB}$	$Beta\_{HML}$	*BM*	*Ivol*	*ROA*	*Ast_gw*	*Inv*	*Lret*	*Sue*	*Momt*
Beta	1											
$Beta\_{MKT}$	0.8224***	1										
$Beta\_{SMB}$	0.2960***	0.0054	1									
$Beta\_{HML}$	−0.2314**	0.1659**	0.0717*	1								
BM	−0.1907**	−0.1027**	0.0027*	0.2787***	1							
Ivol	0.3843***	0.2126**	0.3970***	−0.0874*	−0.0594*	1						
ROA	−0.0446	−0.0296	−0.0896*	−0.0583*	−0.2439**	−0.1071**	1					
Ast_gw	0.1055	0.0609*	0.0393	−0.0970*	−0.1688***	0.0722	0.0233	1				
Inv	0.0442	0.0326	−0.0016	−0.0553	−0.1265**	0.0403	0.0375	0.6400**	1			
Lret	0.0682*	0.0310	0.0211	−0.0892*	−0.2977***	0.0279	0.1470**	0.1981**	0.1596**	1		
Sue	0.0003	0.0063	−0.0725	−0.0570	−0.2491***	−0.0973*	0.3877***	0.0315	0.0107	0.0931*	1	
Momt	−0.0041*	−0.0001*	0.0271*	0.0281*	−0.1753*	−0.0150*	0.1902**	−0.0255	−0.0349	0.0219	0.2625***	1

three real option proxies are consistent with the simulation example in Section 3.1.

Table 3 reports pairwise correlations among our empirical variables. Several interesting patterns emerge. First, asset growth (*Ast_gw*), investment-to-capital ratio (*Inv*), and past long-term return (*Lret*) are highly correlated with one another, suggesting that those anomalies are related, and all seem to capture a long-term return reversal pattern. These three variables are also significantly correlated with *BM*. To the extent that *BM* proxies for the real option, these correlations suggest that asset growth, investment-related, and long-term reversal anomalies could be related to real option features and thus could be partially alleviated if we control for *BM* in our option adjustment. Second, not surprisingly, earnings surprise (*Sue*) and medium-term price momentum (*Momt*) are positively correlated, and they are both correlated with *ROA*, suggesting that earnings and price momentum could be alleviated if we control for ROA in our option adjustment.

Our final sample consists of a panel of monthly stock observations with non-missing real option proxies (*BM*, *Ivol*, *ROA*) from July 1970 through June 2008. There are on average 2,087 stocks each month. We denote this as our full sample. We also consider a subsample in which we further eliminate stocks whose CAPM betas are likely to be estimated with large errors. We use two filters for this purpose. First, we exclude stocks that do not have complete five-year data to estimate betas. Second, we exclude stocks whose CAPM betas are extreme (below the 5th percentile or above the 95th percentile in the cross section). The second filter is similar to what Mamaysky, Spiegel, and Zhang (2008) use in their analysis of mutual fund performance persistence. Altogether, these two filters remove about 14.6% (or 5.3% by market capitalization) of stocks from our full sample. Our subsample thus includes 1,783 stocks per month on average.

4.2. Cross-sectional regression analysis: full sample

When real options are associated with the primitive projects undertaken by the firm, both equity returns and equity betas are complicated functions of these real options, and the CAPM might not hold. Table 4 confirms

Table 4
Cross-sectional regression: full sample.

The dependent variable is monthly excess returns. Independent variables are beta, betas of Fama and French three factors (*Beta_MKT*, *Beta_SMB*, and *Beta_HML*), and the return anomaly variables (*Ast_gw*, *Inv*, *Lret*, *Momt*, and *Sue*). The regression coefficients for the sample period of July 1970 to June 2008 are averaged across time. *T*-Values (in parentheses) are computed using the Fama and MacBeth (1973) procedure and the Newey and West (1987) formula with a lag of 36. Log-transformations are applied to Size and BM. See Table 2 for variable definitions. There are on average 2,087 stocks each month in our full sample.

Model	Constant	*Beta*	*Beta_MKT*	*Beta_SMB*	*Beta_HML*	*Ast_gw*	*Inv*	*Lret*	*Sue*	*Momt*	Adj R^2
1	0.0078	−0.0001	–	–	–	–	–	–	–	–	2.61%
	(4.21)	(−0.09)									
2	0.0084	0.0003	–	–	–	−0.0082	–	–	–	–	2.83%
	(4.57)	(0.21)				(−3.79)					
3	0.0084	0.0001	–	–	–	–	−0.0098	–	–	–	2.83%
	(4.42)	(0.09)					(−2.57)				
4	0.0081	−0.0001	–	–	–	–	–	−0.0012	–	–	3.00%
	(4.50)	(−0.04)						(−2.08)			
5	0.0072	−0.0002	–	–	–	–	–	–	0.0015	–	3.00%
	(3.90)	(−0.12)							(6.59)		
6	0.0066	−0.0004	–	–	–	–	–	–	–	0.0075	3.71%
	(3.71)	(−0.34)								(5.28)	
7	0.0067	–	0.0002	0.0004	0.0022	–	–	–	–	–	4.15%
	(4.19)		(0.21)	(0.46)	(2.64)						
8	0.0074	–	0.0005	0.0004	0.0018	−0.0068	–	–	–	–	4.31%
	(4.62)		(0.47)	(0.53)	(2.29)	(−3.78)					
9	0.0073	–	0.0004	0.0004	0.0019	–	−0.0082	–	–	–	4.32%
	(4.39)		(0.39)	(0.53)	(2.36)		(−2.45)				
10	0.0071	–	0.0004	0.0002	0.0018	–	–	−0.0009	–	–	4.46%
	(4.57)		(0.36)	(0.25)	(2.29)			(−2.19)			
11	0.0061	–	0.0001	0.0006	0.0024	–	–	–	0.0015	–	4.49%
	(3.71)		(0.12)	(0.70)	(2.94)				(7.26)		
12	0.0056	–	0.0000	0.0003	0.0023	–	–	–	–	0.0068	5.03%
	(3.53)		(−0.05)	(0.45)	(3.15)					(5.20)	

the well-documented failure of the CAPM beta to explain the cross-sectional variation in returns. In Model 1, when we regress monthly individual stock excess return (in excess of the risk-free rate) on the CAPM beta, we get a slope coefficient very close to zero and a huge intercept term (78 basis points per month or 9.36% per year).

Models 2–6 confirm the presence of several well-known asset pricing anomalies in our sample. For example, firms with higher asset growth rates are associated with lower stock returns (asset growth anomaly; see Cooper, Gulen, and Schill, 2008); firms with higher investments are associated with lower stock returns (investment-related anomaly; see Anderson and Garcia-Feijoo, 2006; Xing, 2008; Chen, Novy-Marx, and Zhang, 2010); stocks with higher long-term past returns are associated with lower returns (long-term reversal; see DeBondt and Thaler, 1985); stocks with higher returns in the last year have higher current returns (price momentum; see Jegadeesh and Titman, 1993); and stocks with positive earnings surprises have higher returns (earnings momentum; see Benard and Thomas, 1990). The CAPM beta is not significant at all in the presence of these anomalies.

Models 7–12 add the Fama and French three factor betas estimated using the standard five-year $[t-60, t-1]$ rolling window. While the HML factor beta becomes significant, the MKT factor beta remains insignificant and is associated with a close-to-zero risk premium. In addition, all five anomalies remain to be significant after the inclusion of two additional SMB and HML factor betas.

Under our main hypothesis, if the failure of the CAPM on equity return is driven by real options, then removing the effect of real options from equity returns and betas should improve the performance of the CAPM. We follow the procedure described in Section 3 to conduct real option adjustment using a cross-sectional regression. In the first-stage regression, we regress the monthly (excess) stock return or the factor loadings (including the CAPM beta) on the three real option proxies (*BM*, *Ivol*, and *ROA*). All three variables are measured in terms of the excess over their counterparts for the market portfolio, and the regression has no intercept term. These procedures ensure that the CAPM relation holds for the market portfolio. The residuals from these regressions are the option-adjusted (excess) returns and option-adjusted betas. Given the fact that true real options, which are not directly observable, affect both returns and betas in highly complicated and nonlinear fashion, our simple regression approach might not fully remove real option effects. Yet to the extent that our real option proxies correlate with the true real options, the option-adjusted (excess) returns and option-adjusted betas from the first-stage regression should more closely resemble the risk premium and betas of the underlying primitive projects. If so, the CAPM should perform better after real option adjustments.

Table 5 reports results of the regression analysis in Table 4 but after the first-stage real option adjustments. In Model 1, we find the option-adjusted CAPM beta becomes significantly and positively related to the

Table 5
Cross-sectional regression after real option adjustment: full sample.

The dependent variable is the option-adjusted monthly excess return. Independent variables are beta, betas of Fama and French three factors (*Beta_MKT*, *Beta_SMB*, and *Beta_HML*), and the return anomaly variables (*Ast_gw*, *Inv*, *Lret*, *Momt*, and *Sue*). The regression coefficients for the sample period of July 1970 to June 2008 are averaged across time. *T*-Values (in parentheses) are computed using the Fama and MacBeth (1973) procedure and the Newey and West (1987) formula with a lag of 36. Log-transformations are applied to *Size* and *BM*. The option-adjusted variables are constructed as the residuals from regressing the raw variables with independent variables of *BM*, *Ivol*, and *ROA*. See Table 2 for variable definitions. There are on average 2,087 stocks each month in our full sample.

Model	Constant	*Beta*	*Beta_MKT*	*Beta_SMB*	*Beta_HML*	*Ast_gw*	*Inv*	*Lret*	*Sue*	*Momt*	Adj R^2 (%)
1	0.0020	0.0042	–	–	–	–	–	–	–	–	3.90
	(3.14)	(3.35)									
2	0.0021	0.0046	–	–	–	−0.0043	–	–	–	–	4.08
	(3.38)	(3.98)				(−2.34)					
3	0.0020	0.0045	–	–	–	–	−0.0048	–	–	–	4.09
	(3.25)	(3.74)					(−1.49)				
4	0.0019	0.0044	–	–	–	–	–	−0.0004	–	–	4.16
	(3.60)	(3.67)						(−0.94)			
5	0.0016	0.0035	–	–	–	–	–	–	0.0016	–	4.10
	(2.78)	(2.79)							(9.75)		
6	0.0014	0.0031	–	–	–	–	–	–	–	0.0080	4.78
	(2.61)	(2.66)								(6.52)	
7	0.0016	–	0.0041	0.0017	0.0009	–	–	–	–	–	4.97
	(3.06)		(3.58)	(1.98)	(1.43)						
8	0.0017	–	0.0045	0.0018	0.0007	−0.0041	–	–	–	–	5.12
	(3.33)		(4.24)	(2.17)	(1.13)	(−2.32)					
9	0.0017	–	0.0044	0.0018	0.0007	–	−0.0047	–	–	–	5.12
	(3.18)		(4.00)	(2.15)	(1.15)		(−1.65)				
10	0.0016	–	0.0044	0.0017	0.0007	–	–	−0.0005	–	–	5.19
	(3.53)		(4.05)	(1.92)	(1.21)			(−1.21)			
11	0.0013	–	0.0034	0.0016	0.0009	–	–	–	0.0016	–	5.15
	(2.66)		(2.96)	(1.86)	(1.51)				(9.82)		
12	0.0011	–	0.0031	0.0014	0.0007	–	–	–	–	0.0073	5.67
	(2.48)		(2.85)	(1.71)	(1.40)					(6.21)	

option-adjusted (excess) stock return. The slope coefficient is 42 basis points per month (or 5.04% per year with a *t*-value of 3.11). In addition, the intercept term drops from 78 bps per month in Table 4 to 20 bps per month (or 2.40% per year), which is still significant (*t*-value = 3.14).

Models 2–6 find the option-adjusted CAPM beta to be still highly significant (with *t*-values usually above 2.6) even in the presence of the anomaly variables. Interestingly, the option-adjusted CAPM beta helps to weaken or even drive out several anomalies that are associated with long-term stock price mean reversion (*Ast_gw*, *Inv*, and *Lret*). For instance, after real option adjustment, the *t*-value associated with asset growth (*Ast_gw*) drops from −3.79 (in Table 4) to −2.34. Furthermore, investment-to-capital ratio (*Inv*) and past long-term return (*Lret*) become insignificant with *t*-values of −1.49 and −0.94, respectively. This result is consistent with recent findings by Cooper and Priestley (2010), which suggest that firms' real options are likely driving the asset growth and investment-related anomalies. Meanwhile the real option adjustment has little impact on anomalies that are related to short-term return continuation. Both price and earnings momentum (*Momt* and *Sue*) remain highly significant. Additional unreported diagnostic tests confirm that both anomalies, at monthly frequency, are driven by components in *Momt* and *Sue* that are orthogonal to *ROA*. To the extent that short-term price continuation typically does not persist beyond a few quarters and requires frequent portfolio rebalancing, it is probably less relevant for the cost of capital calculation for a project whose life usually goes beyond five years. Models 7–12 again include the Fama and French three-factor betas after the real option adjustment. The CAPM beta now drives out the factor loading on HML in explaining option-adjusted stock returns.

Our analysis so far suffers from the standard errors-in-variables problem as the time series estimation of betas introduces measurement errors. Kim (1995) shows that the problem leads to a lower risk premium estimate and a higher intercept estimate in the cross-sectional regression, potentially explaining why we find that the slope coefficient is smaller than the market risk premium and the intercept term is significantly different from zero. Following Jagannathan, Kim, and Skoulakis (2010), we directly correct the biased cross-sectional regression estimates for the errors-in-variables problem. The details of the correction are presented in the Internet Appendix. The bias-corrected regression coefficients and their *t*-values are reported in Table 6.

A comparison of the results in Table 6 and those in Table 5 shows that bias correction in general increases the slope estimates on the CAPM beta and reduces the intercept estimates. For example, in Model 1, a single CAPM beta receives a slope estimate of 53 bps per month (or 6.36% per year), closer to the historical annual market risk premium of about 8.00% in the US. In fact, the slope coefficient of 6.36% per year is not significantly different from 8.00%. In addition, the intercept term drops to 14 bps (or 1.68% per year) and becomes less significant (*t*-value = 2.45). With the Fama

Table 6
Bias-corrected cross-sectional regression with real option adjustment: full sample.

The dependent variable is option-adjusted monthly excess returns. Independent variables are beta, betas of Fama and French three-factors (*Beta_MKT*, *Beta_SMB*, and *Beta_HML*), and the return anomaly variables. The regression coefficients for the sample period of July 1970 to June 2008 are first corrected using procedures described in the Internet Appendix and averaged across time. *T*-Values (in parentheses) are computed using the Fama and MacBeth (1973) procedure and the Newey and West (1987) formula with a lag of 36. Log-transformations are applied to *Size* and *BM*. The option-adjusted variables are constructed as the residuals from regressing the raw variables with independent variables of *BM*, *Ivol*, and *ROA*. See Table 2 for variable definitions. There are on average 2,087 stocks each month in our full sample.

Model	Constant	*Beta*	*Beta_MKT*	*Beta_SMB*	*Beta_HML*	*Ast_gw*	*Inv*	*Lret*	*Sue*	*Momt*	Adj R^2 (%)
1	0.0014	0.0053	–	–	–	–	–	–	–	–	1.80
	(2.45)	(3.42)									
2	0.0014	0.0061	–	–	–	−0.0057	–	–	–	–	1.99
	(2.56)	(4.05)				(−3.26)					
3	0.0014	0.0059	–	–	–	–	−0.0065	–	–	–	1.96
	(2.54)	(3.80)					(−1.94)				
4	0.0013	0.0058	–	–	–	–	–	−0.0006	–	–	1.96
	(2.72)	(3.73)						(−1.38)			
5	0.0012	0.0045	–	–	–	–	–	–	0.0016	–	1.94
	(2.18)	(2.82)							(8.49)		
6	0.0009	0.0039	–	–	–	–	–	–	–	0.0083	2.77
	(1.98)	(2.70)								(7.13)	
7	0.0006	–	0.0054	0.0024	0.0030	–	–	–	–	–	1.18
	(1.96)		(3.53)	(1.47)	(1.82)						
8	0.0007	–	0.0059	0.0025	0.0026	−0.0045	–	–	–	–	1.23
	(2.16)		(4.06)	(1.57)	(1.66)	(−2.94)					
9	0.0007	–	0.0058	0.0026	0.0026	–	−0.0056	–	–	–	1.30
	(2.12)		(3.87)	(1.60)	(1.66)		(−2.18)				
10	0.0007	–	0.0059	0.0024	0.0028	–	–	−0.0007	–	–	1.28
	(2.20)		(3.96)	(1.48)	(1.71)			(−2.08)			
11	0.0005	–	0.0046	0.0023	0.0028	–	–	–	0.0013	–	1.34
	(1.56)		(2.96)	(1.45)	(1.80)				(8.34)		
12	0.0004	–	0.0039	0.0029	0.0035	–	–	–	–	0.0049	1.71
	(1.48)		(2.54)	(1.66)	(1.67)					(2.52)	

and French three-factor model (Model 7), the intercept term becomes even smaller at 6 bps per month (or 0.72% per year).

Fig. 2 demonstrates the effect of option adjustment on selected portfolios. We compare the results of the portfolio average annualized excess returns plotted against portfolio average betas (left-hand panel) with those of the portfolio average option-adjusted excess returns against portfolio average option-adjusted betas (right-hand panel). The regression estimates are presented below the plots. In Panel A, based on results for the 25 book-to-market and size-sorted portfolios, the failure of the CAPM without option adjustment is evident in the left plot. The intercept term is huge, while the slope coefficient is small and even negative. The improvement in the performance of the CAPM after the option adjustment is significant as seen in the right plot. The intercept term becomes much smaller (dropping from 13.19% to 1.09%), and the slope coefficient of 7.60% becomes significant. Furthermore, the *R*-square increases from less than 4% to almost 60%.

Panel B examines the Fama and French 48 industry portfolios and underlies similar conclusions. In the case of regression of portfolio excess returns on portfolio betas, the intercept term is huge and significant, while the slope coefficient is small and insignificant. The option adjustment again improves the regression. In the case of regression of option-adjusted portfolio excess returns on option-adjusted portfolio betas, the intercept term becomes close to zero and insignificant (dropping from 8.33% to 0.11%), and the slope coefficient of 6.19% becomes very significant. Furthermore, the *R*-square improves from less than 1% to almost 19%.

4.3. Cross-sectional regression analysis: subsample

Table 7 reports the bias-corrected regression results for our subsample, after excluding about 14.6% of stocks in the full sample whose CAPM betas are likely to be estimated with large errors, by following the procedures described in Mamaysky, Spiegel, and Zhang (2008). Removing these stocks further strengthens support for the CAPM after real option adjustment. For example, in Model 1, a single CAPM beta receives a slope estimate of 65 bps per month (or 7.80% per year), very close to the historical market risk premium of about 8.00% in the US. In addition, the intercept term drops to 8 bps per month (or 0.96% per year) and becomes insignificant (t-value = 1.61). For the Fama and French three-factor model (Model 7), the intercept term becomes even lower at 2 bps per month (or 0.24% per year) and insignificant. We again find that real option adjustment helps to weaken or even drive out several anomalies that are associated with long-term stock price mean reversion (*Ast_gw*, *Inv*, and *Lret*).

We thus provide direct evidence suggesting that the failure of the CAPM to explain stock returns is likely attributable to the real options effect. Once these real

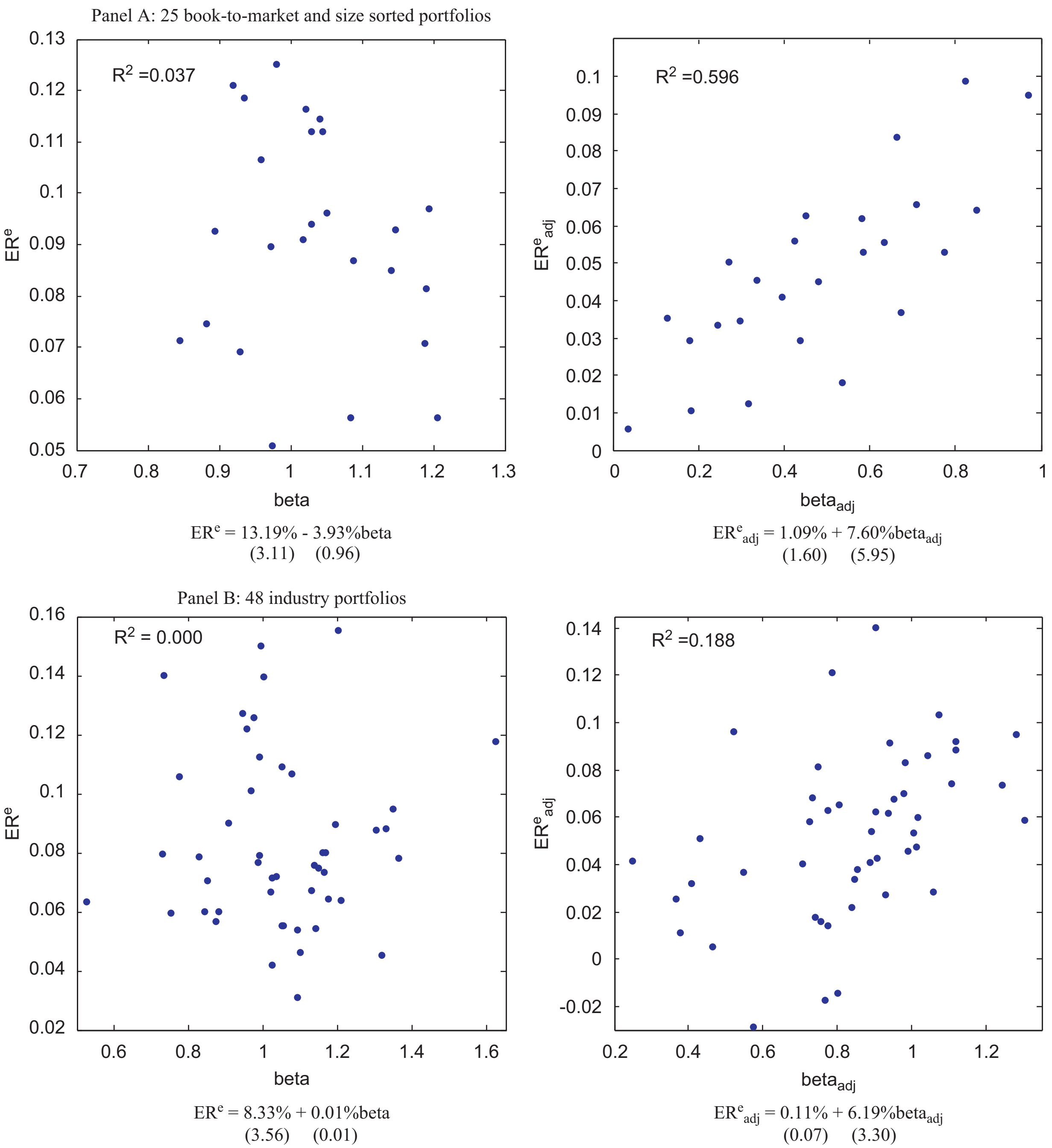

Fig. 2. Portfolio excess returns and portfolio betas. Left-hand-side graphs plot portfolio average monthly excess returns (ER^e) against portfolio average betas. Right-hand-side graphs plot portfolio average option-adjusted excess returns (ER^e_{adj}) against portfolio average option-adjusted betas. The regression estimates of excess returns on betas are presented below the plots. Panel A examines 25 portfolios sorted on book-to-market and size, and Panel B examines 48 industry portfolios constructed using the Fama and French industry classifications. The option-adjusted variables are constructed as the residuals from regressing the raw variables with independent variables of *BM*, *Ivol*, and *ROA*. Variable definitions are in Table 2.

options are removed, the CAPM works reasonably well in explaining the risk premium on the primitive projects. The Internet Appendix contains robustness results from additional regressions where we drop one real option proxy at a time. We find our main conclusion to be robust to the exclusion of any of the three proxies.

5. Conclusion

We have evaluated the empirical evidence against the standard CAPM from the perspective that it can nevertheless provide a reasonable estimate of a project's cost of capital. To do this, we differentiate the required expected

Table 7
Bias-corrected cross-sectional regression with option adjustment: subsample.

Cross-sectional regression analysis is conducted on the subsample of stocks after excluding stocks whose betas are likely estimated with large errors. The dependent variable is the optioned-adjusted monthly excess returns; independent variables are beta, betas of Fama and French three factors (*Beta_MKT*, *Beta_SMB*, and *Beta_HML*) and the return anomaly variables. The regression coefficients for the sample period of July 1970 to June 2008 are first corrected using procedures described in the Internet Appendix and averaged across time. *T*-Values (in parentheses) are computed using the Fama and MacBeth (1973) procedure and the Newey and West (1987) formula with a lag of 36. Log-transformations are applied to *Size* and *BM*. The option-adjusted variables are constructed as the residuals from regressing the raw variables with independent variables of *BM*, *Ivol*, and *ROA*. See Table 2 for variable definitions. There are on average 1,783 stocks each month in our subsample.

Model	Constant	*Beta*	*Beta_MKT*	*Beta_SMB*	*Beta_HML*	*Ast_gw*	*Inv*	*Lret*	*Sue*	*Momt*	Adj R^2 (%)
1	0.0008	0.0065	–	–	–	–	–	–	–	–	1.64
	(1.61)	(3.75)									
2	0.0008	0.0074	–	–	–	−0.0054	–	–	–	–	1.85
	(1.57)	(4.31)				(−3.11)					
3	0.0008	0.0072	–	–	–	–	−0.0065	–	–	–	1.80
	(1.61)	(4.05)					(−1.76)				
4	0.0007	0.0071	–	–	–	–	–	−0.0005	–	–	1.80
	(1.62)	(4.05)						(−1.38)			
5	0.0007	0.0056	–	–	–	–	–	–	0.0015	–	1.87
	(1.46)	(3.10)							(7.97)		
6	0.0005	0.0047	–	–	–	–	–	–	–	0.0087	2.67
	(1.28)	(2.98)								(7.75)	
7	0.0002	–	0.0063	0.0024	0.0024	–	–	–	–	–	0.83
	(0.60)		(3.42)	(1.36)	(1.24)						
8	0.0002	–	0.0069	0.0025	0.0022	−0.0040	–	–	–	–	0.99
	(0.63)		(3.73)	(1.45)	(1.12)	(−2.77)					
9	0.0002	–	0.0068	0.0026	0.0021	–	−0.0053	–	–	–	0.89
	(0.72)		(3.58)	(1.49)	(1.07)		(−1.78)				
10	0.0002	–	0.0070	0.0024	0.0021	–	–	−0.0006	–	–	0.97
	(0.63)		(3.80)	(1.38)	(1.08)			(−2.34)			
11	0.0001	–	0.0054	0.0024	0.0023	–	–	–	0.0012	–	1.01
	(0.33)		(2.90)	(1.36)	(1.20)				(7.30)		
12	0.0001	–	0.0060	0.0006	−0.0017	–	–	–	–	0.0074	1.36
	(0.29)		(3.32)	(0.27)	(−0.42)					(4.34)	

return on potential primitive projects available to a firm from the required expected return on a firm's stocks.

We find that a firm's embedded real option to modify and abandon established projects and undertake new projects could be an important reason behind the poor performance of the CAPM in explaining the cross section of returns on size- and book-to-market-sorted stock portfolios. This lends support to the Berk, Green, and Naik (1999) observation that stock returns need not satisfy the CAPM even when the expected returns on all individual projects do.

We propose a cross-sectional regression method for constructing the option-adjusted returns of firms and the corresponding project betas. We provide simulation and empirical evidence supporting the use of the method. When we compute project betas using the cross-sectional regression procedure, we find that the CAPM does a reasonable job in explaining option-adjusted stock returns at the individual stock level.

Levy and Roll (2010) make the interesting observation that small variations in the values of sample parameters can make commonly used market proxies mean variance efficient, and "the CAPM (i.e., ex ante mean/variance efficiency of the market index proxy) is consistent with the empirically observed return parameters and the market proxy portfolio weights." In this paper we provide an alternative explanation for the continued use of the CAPM by finance professionals. Our findings support the view that the CAPM provides a reasonable estimate of a project's cost of capital, provided that any embedded real options associated with the project are evaluated separately for capital budgeting purposes.

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