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# A neoclassical interpretation of momentum

Laura Xiaolei Liu [a,b,1], Lu Zhang [c,d,*]

[a] School of Business and Management, Hong Kong University of Science and Technology, Hong Kong
[b] Guanghua School of Management, Peking University, China
[c] Fisher College of Business, The Ohio State University, 760A Fisher Hall, 2100 Neil Avenue, Columbus, OH 43210, United States
[d] National Bureau of Economic Research, United States

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ABSTRACT

The neoclassical theory of investment implies that expected stock returns are tied with the expected marginal benefit of investment divided by the marginal cost of investment. Winners have higher expected growth and expected marginal productivity (two major components of the marginal benefit of investment), and earn higher expected stock returns than losers. The investment model succeeds in capturing average momentum profits, reversal of momentum in long horizons, long-run risks in momentum, and the interaction of momentum with several firm characteristics. However, the model fails to reproduce the procyclicality of momentum as well as its negative interaction with book-to-market equity.

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## 1. Introduction

Momentum is a major anomaly in financial economics and accounting. Bernard and Thomas (1989) document that stocks with high earnings surprises earn higher average returns over the next twelve months than stocks with low earnings surprises (earnings momentum), and conclude that their evidence "cannot plausibly be reconciled with arguments built on risk mismeasurement but is consistent with a delayed price response (p. 34)."[2] Jegadeesh and Titman (1993) document that stocks with high recent performance continue to earn higher average returns over the next three to twelve months than stocks with low recent performance (price momentum), and suggest that "the market underreacts to information about the short-term prospects of firms (p. 90)."[3] The bulk of the momentum literature has adopted the behavioral interpretation.

* Corresponding author at: Fisher College of Business, The Ohio State University, 760A Fisher Hall, 2100 Neil Avenue, Columbus, OH 43210, United States. Tel.: +1 614 292 8644; fax: +1 614 292 7062.

*E-mail addresses:* fnliu@ust.hk (L.X. Liu), zhanglu@fisher.osu.edu (L. Zhang).

[1] Tel.: +852 2358 7661; fax: +852 2358 1749.

[2] A voluminous empirical literature documents earnings momentum, which is also referred to as post-earnings announcement drift in the accounting literature. Ball and Brown (1968) first observe the drift. Many subsequent studies have documented this anomaly more precisely in different samples and explored different explanations (e.g., Foster et al., 1984; Bernard and Thomas, 1990; Chan et al., 1996).

[3] Many subsequent studies have confirmed and refined price momentum. Asness (1997) shows that momentum is stronger in growth firms than in value firms. Rouwenhorst (1998), Hou et al. (2011), and Fama and French (2012) document momentum profits in international markets. Moskowitz and Grinblatt (1999) report large momentum profits in industry portfolios. Several studies document interactions of momentum with characteristics such as size, analyst coverage, trading volume, firm age, stock return volatility, and credit ratings (e.g., Hong et al., 2000; Lee and Swaminathan, 2000; Jiang et al., 2005; Zhang, 2006; Avramov et al., 2007). Jegadeesh and Titman (2001) show that momentum remains large in the post-1993 sample. Finally, Asness et al. (2013) report consistent value and momentum profits across eight diverse markets and asset classes including country equity index futures, government bonds, currencies, and commodity futures.

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In particular, Barberis et al. (1998), Daniel et al. (1998), and Hong and Stein (1999) have constructed behavioral models to explain momentum using conservatism, self-attributive overconfidence, and slow information diffusion, respectively.

As a fundamental departure from the existing literature, this paper uses the neoclassical theory of investment to examine whether momentum is correctly connected to economic fundamentals through the first principles of firms. The answer is, perhaps surprisingly, affirmative. Under constant returns to scale, the stock return equals the (levered) investment return. The investment return, defined as the next-period marginal benefit of investment divided by the current-period marginal cost of investment, is tied with firm characteristics via the first principles. Intuitively, winners have higher expected growth and higher expected profitability, which are two major components of the expected marginal benefit of investment. As such, winners earn higher expected stock returns than losers.

The structural model is estimated via generalized method of moments (GMM) by matching average levered investment returns to average stock returns across momentum portfolios. For price momentum, the winner-minus-loser decile has a small model error (alpha) of 0.40% per annum, which is only 2.65% of the average winner-minus-loser return of 15.09%. Also, the mean absolute error across the deciles is 0.83%, which is 6.69% of the average decile return of 12.40%. For earnings momentum, the winner-minus-loser decile has an alpha of −0.92%, which is 10.86% of the average winner-minus-loser return of 8.47%. The mean absolute error across the deciles is 0.63%, which is only 4.12% of the average decile return of 15.26%. The expected investment-to-capital growth is the most important component of momentum. Without its cross-sectional variation, the winner-minus-loser alpha jumps from 0.40% in the benchmark estimation to 9.92% for price momentum, and from −0.92% to 4.07% for earnings momentum.

The investment model is also consistent with the short-lived nature of momentum. In particular, the price momentum winner-minus-loser decile in the data starts at 19.98% per annum in the first month after the portfolio formation, falls to 13.15% in month six, converges to zero in month ten, and turns negative afterward. Similarly, the winner-minus-loser return in the model starts at 18.21% in the first month, falls to 10.73% in month six, converges to zero in month fifteen, and turns negative afterward. In addition, the low persistence of the expected investment-to-capital growth is the underlying force of this reversal. The expected growth spread between winners and losers starts at 39.45% in month one, drops to 23.06% in month six, converges to zero in month thirteen, and turns negative afterward. In contrast, the profitability spread between winners and losers is much more persistent.

The investment model goes a long way toward fitting the average returns across two-way portfolios from interacting momentum with firm characteristics such as size, age, trading volume, credit ratings, and stock return volatility. Although occasionally large, the investment alphas do not vary systematically with either price or earnings momentum. However, the model fails to capture the negative interaction between momentum and book-to-market. The winner-minus-loser alphas for price momentum across the low, median, and high book-to-market terciles are 3.46%, −0.70%, and −6.80% per annum, respectively, which vary inversely with book-to-market. More important, the high-minus-low alphas across the loser, median, and winner price momentum terciles are 11%, 10.07%, and 0.73% per annum, respectively, which vary strongly with momentum. In addition, contrary to Cooper et al. (2004), momentum in the model is not higher following up than down markets. Finally, the investment returns across the price momentum deciles display long-run risks similar to the stock returns in Bansal et al. (2005).

Cochrane (1991) uses the investment model to study aggregate asset prices. Belo (2010) uses the marginal rate of transformation as a stochastic discount factor. Jermann (2010, 2013) uses the investment model to study the equity premium and the term structure of interest rates. Berk et al. (1999), Johnson (2002), Sagi and Seasholes (2007), and Li (2014) construct dynamic investment models to account for momentum quantitatively. Our work differs by doing structural estimation on closed-form investment return equations with real data. Built on Liu et al. (2009), our work differs by focusing on momentum. It also contains a more polished timing alignment procedure that allows us to construct monthly investment returns out of annual accounting data to match with monthly stock returns. This methodological innovation increases the power of our tests substantially.

The rest of the paper unfolds as follows. Section 1 sets up the model. Section 2 describes our econometric design. Section 3 presents our estimation results. Section 4 concludes.

## 2. The investment model

Firms use capital and costlessly adjustable inputs to produce a homogeneous output. These inputs are chosen each period to maximize operating profits, defined as revenue minus the expenditure on these inputs. Taking operating profits as given, firms choose investment to maximize the market value of equity.

Let $\Pi(K_{it}, X_{it})$ denote the operating profits of firm $i$ at time $t$, in which $K_{it}$ is capital, and $X_{it}$ is a vector of exogenous aggregate and firm-specific shocks. $\Pi(K_{it}, X_{it})$ exhibits constant returns to scale, i.e., $\Pi(K_{it}, X_{it}) = K_{it}\partial\Pi(K_{it}, X_{it})/\partial K_{it}$. In addition, firms have a Cobb–Douglas production function, meaning that the marginal product of capital is $\partial\Pi(K_{it}, X_{it})/\partial K_{it} = \kappa Y_{it}/K_{it}$, in which $\kappa > 0$ is the capital's share in output, and $Y_{it}$ is sales. Capital evolves as $K_{it+1} = I_{it} + (1-\delta_{it})K_{it}$, in which $\delta_{it}$ is the exogenous proportional rate of capital depreciation and is firm-specific and time-varying. Firms incur adjustment costs when investing. The adjustment cost function, denoted $\Phi(I_{it}, K_{it})$, is increasing and convex in $I_{it}$, decreasing in $K_{it}$, and of constant returns to scale in $I_{it}$ and $K_{it}$. Specifically, it has a quadratic form: $\Phi(I_{it}, K_{it}) = (a/2)\,(I_{it}/K_{it})^2 K_{it}$, in which $a > 0$.

At the beginning of time $t$, firm $i$ issues debt, $B_{it+1}$, which must be repaid at the beginning of $t+1$. When borrowing, firms take as given the gross risky interest rate on $B_{it}$, denoted $r^B_{it}$, which varies across firms and over time. Taxable corporate profits equal operating profits less capital depreciation, adjustment costs, and interest expenses, $\Pi(K_{it}, X_{it}) - \delta_{it}K_{it} - \Phi(I_{it}, K_{it}) - (r^B_{it} - 1)B_{it}$. Let $\tau_t$ be the corporate tax rate, $\tau_t \delta_{it} K_{it}$ be the depreciation tax shield, and $\tau_t(r^B_i - 1)B_{it}$ be the interest tax shield. Then firm $i$'s payout is given by $D_{it} \equiv (1-\tau_t)[\Pi(K_{it}, X_{it}) - \Phi(I_{it}, K_{it})] - I_{it} + B_{it+1} - r^B_{it}B_{it} + \tau_t \delta_{it} K_{it} + \tau_t (r^B_{it} - 1)B_{it}$.

Let $M_{t+1}$ be the stochastic discount factor from $t$ to $t+1$. Taking $M_{t+1}$ as given, firm $i$ maximizes its cum-dividend market value of equity, $V_{it} \equiv \max_{\{I_{it+\Delta t}, K_{it+\Delta t+1}, B_{it+\Delta t+1}\}_{\Delta t=0}^{\infty}} E_t[\sum_{\Delta t=0}^{\infty} M_{t+\Delta t} D_{it+\Delta t}]$, subject to a transversality condition: $\lim_{T\to\infty} E_t[M_{t+T} \ B_{it+T+1}] = 0$. The firm's first-order condition for investment implies $E_t[M_{t+1} r^I_{it+1}] = 1$, in which $r^I_{it+1}$ is the investment return:

$$r^I_{it+1} \equiv \frac{(1-\tau_{t+1})\left[\kappa \frac{Y_{it+1}}{K_{it+1}} + \frac{a}{2}\left(\frac{I_{it+1}}{K_{it+1}}\right)^2\right] + \tau_{t+1}\delta_{it+1} + (1-\delta_{it+1})\left[1 + (1-\tau_{t+1})a\left(\frac{I_{it+1}}{K_{it+1}}\right)\right]}{1 + (1-\tau_t)a\left(\frac{I_{it}}{K_{it}}\right)}. \tag{1}$$

Intuitively, the investment return is the marginal benefit of investment at $t+1$ divided by the marginal cost of investment at $t$. The optimality condition says that the marginal cost of investment equals the marginal benefit of investment discounted to $t$. In the numerator of the investment return, $(1-\tau_{t+1})\kappa(Y_{it+1}/K_{it+1})$ is the after-tax marginal product of capital, $(1-\tau_{t+1})(a/2)(I_{it+1}/K_{it+1})^2$ is the after-tax marginal reduction in adjustment costs, and $\tau_{t+1}\delta_{it+1}$ is the marginal depreciation tax shield. The last term in the numerator is the marginal continuation value of an extra unit of capital net of depreciation, in which the marginal continuation value equals the marginal cost of investment in the next period, $1 + (1-\tau_{t+1})a(I_{it+1}/K_{it+1})$.

Define the after-tax corporate bond return as $r^{Ba}_{it+1} \equiv r^B_{it+1} - (r^B_{it+1} - 1)\tau_{t+1}$. Firm $i$'s first-order condition for new debt implies $E_t[M_{t+1} r^{Ba}_{it+1}] = 1$. Define $P_{it} \equiv V_{it} - D_{it}$ as the ex-dividend market value of equity, $r^S_{it+1} \equiv (P_{it+1} + D_{it+1})/P_{it}$ as the stock return, and $w_{it} \equiv B_{it+1}/(P_{it} + B_{it+1})$ as the market leverage. The investment return then equals the weighted average of the stock return and the after-tax corporate bond return, $r^I_{it+1} = w_{it} r^{Ba}_{it+1} + (1-w_{it}) r^S_{it+1}$ (see Liu et al. (2009), Appendix A). Solving for the stock return, $r^S_{it+1}$, yields

$$r^S_{it+1} = r^{Iw}_{it+1} \equiv \frac{r^I_{it+1} - w_{it}\, r^{Ba}_{it+1}}{1 - w_{it}}, \tag{2}$$

in which $r^{Iw}_{it+1}$ is the levered investment return. If $w_{it} = 0$, Eq. (2) collapses to the equivalence between the stock return and the investment return, a relation due to Cochrane (1991).

Combining Eq. (1) with $r^I_{it+1} = w_{it} r^{Ba}_{it+1} + (1-w_{it}) r^S_{it+1}$ provides the microfoundation for the weighted average cost of capital approach to capital budgeting in corporate finance:

$$1 + (1-\tau_t)a\left(\frac{I_{it}}{K_{it}}\right) = \frac{(1-\tau_{t+1})\left[\kappa \frac{Y_{it+1}}{K_{it+1}} + \frac{a}{2}\left(\frac{I_{it+1}}{K_{it+1}}\right)^2\right] + \tau_{t+1}\delta_{it+1} + (1-\delta_{it+1})\left[1 + (1-\tau_{t+1})a\left(\frac{I_{it+1}}{K_{it+1}}\right)\right]}{w_{it} r^{Ba}_{it+1} + (1-w_{it}) r^S_{it+1}}. \tag{3}$$

Intuitively, firm $i$ chooses investment so that the benefit of an additional unit of investment at $t+1$ (the numerator of the right-hand side of Eq. (3)) discounted by the weighted average cost of capital equals the cost of the additional unit of investment (the left-hand side of the equation). As such, the net present value of the last infinitesimal project is zero.

## 3. Econometric design

Section 3.1 presents our GMM tests, and Section 3.2 describes our data.

### 3.1. GMM estimation and tests

Our structural estimation tests the first moment restriction implied by Eq. (2):

$$E[r^S_{it+1} - r^{Iw}_{it+1}] = 0. \tag{4}$$

In particular, the model error (alpha) from the investment model is defined as $\alpha^q_i \equiv E_T[r^S_{it+1} - r^{Iw}_{it+1}]$, in which $E_T[\cdot]$ is the sample mean of the series in the brackets.

#### 3.1.1. Econometric methodology

Our estimation uses one-stage GMM with the identity weighting matrix to preserve the economic structure of testing portfolios. The parameters, $\mathbf{b} \equiv (a, \kappa)$, are obtained by minimizing a weighted combination of the sample moments (4).[4]

To keep the model parsimonious, an implicit assumption is that different firms have identical production and capital adjustment technologies. This aggregation assumption is extreme, but does help guard against the proliferation of free parameters. Introducing more parameters, such as making the two parameters industry-specific, is likely to only improve the model's fit. Due to the likely technological heterogeneity across industries in the data, the $\kappa$ and $a$ estimates should be interpreted as the average estimates across industries. Finally, our aggregation assumption is no more extreme than the assumption underlying the representative agent construct in the consumption model (e.g., Hansen and Singleton, 1982). The construct essentially assumes that all consumers in the economy have identical preferences.

#### 3.1.2. Comparison with the consumption model

Our test on Eq. (4) differs from the standard test in the consumption framework. Written recursively at the optimum, the value function becomes $V_{it} = D_{it} + E_t[M_{t+1} V_{it+1}]$, or $1 = E_t[M_{t+1} r^S_{it+1}]$ with $r^S_{it+1} = V_{it+1}/(V_{it} - D_{it})$, which gives the moment condition in the standard test. The standard test calls for the parametrization of the pricing kernel, $M_{t+1}$. Our test differs because it does not take a stand on the functional form of $M_{t+1}$, while linking stock returns directly with firm-level fundamentals.

Built on the investment first-order condition, our test asks whether managers adjust their investment policies optimally per the costs of capital. If affirmative, the cross-sectional variation in the expected levered investment returns should be aligned with the cross-sectional variation in the expected stock returns. In contrast, built on the consumption first-order condition, the standard test asks whether consumers adjust their consumption-portfolio choice policies optimally per the expected returns of different assets. If affirmative, the cross-sectional variation in the consumption risk should be aligned with the cross-sectional variation in the expected stock returns.

Conceptually, the investment model and the consumption model are complementary. One approach does not have to perform better empirically than the other to be economically interesting. While immune to measurement difficulties in the consumption data, the investment approach is silent about sources of risk. However, built on the weighted average cost of capital approach to capital budgeting, which is standard in corporate finance, the investment approach tries to back out the discount rates from the observable investment decisions of firms. Doing so allows us to estimate the expected stock returns without being hampered by the empirical difficulties of the consumption model.

### 3.2. Data

Firm-level data are from the Center for Research in Security Prices (CRSP) monthly stock file and the annual 2012 Standard and Poor's Compustat industrial files. Firms with primary SIC classifications between 4900 and 4999 (regulated firms) or between 6000 and 6999 (financial firms) are excluded. The sample is from 1963 to 2012. The sample includes only firm-year observations with positive total assets, positive sales, nonnegative debt, positive market value of assets (the book value of debt plus the market value of equity), and positive capital stock at the most recent fiscal yearend as of portfolio formation, as well as positive capital stock one year prior to the most recent fiscal year. This sample selection criterion is imposed because the data items are required to calculate levered investment returns.

#### 3.2.1. Testing portfolios

The benchmark testing portfolios are deciles formed on price momentum and on earnings momentum. To construct the price momentum deciles, stocks are sorted at the end of each month $t$ on their prior six-month returns from $t-6$ to $t-1$, denoted $R^6$, and the resulting deciles are held for six months from $t+1$ to $t+6$. To avoid microstructure biases, the holding period skips month $t$ between the end of the ranking period and the beginning of the holding period. As in Jegadeesh and Titman (1993), stocks with prices per share less than \$5 at the portfolio formation month are excluded, and all stocks are equal-weighted within a given portfolio. The six-month holding period means that there are six sub-portfolios for each decile in a given month. The returns for these six sub-portfolios are averaged to obtain the monthly returns of a given decile.

As in Chan et al. (1996), the standardized unexpected earnings, denoted SUE, is computed as the change in quarterly earnings per share (Compustat quarterly item EPSPXQ) from its value four quarters ago divided by the standard deviation of the change in quarterly earnings per share over the prior eight quarters. At the end of each month $t$, all the NYSE, Amex, and Nasdaq stocks are ranked into deciles based on the SUE calculated with the most recently announced earnings. Equal-weighted monthly returns over the subsequent six months from $t+1$ to $t+6$ are calculated for the portfolios, which are in

[4] Let $\mathbf{g}_T$ be the sample moments. The GMM objective function is a weighted sum of squares of the model errors across a given set of assets, $\mathbf{g}_T' \mathbf{W} \mathbf{g}_T$, in which $\mathbf{W} = \mathbf{I}$, the identity matrix. Let $\mathbf{D} = \partial \mathbf{g}_T / \partial \mathbf{b}$ and $\mathbf{S}$ a consistent estimate of the variance–covariance matrix of the sample errors, $\mathbf{g}_T$. We estimate $\mathbf{S}$ using a standard Bartlett kernel with a window length of five. The estimate of $\mathbf{b}$, denoted $\hat{\mathbf{b}}$, is asymptotically normal with the variance–covariance matrix given by $\mathrm{var}(\hat{\mathbf{b}}) = (\mathbf{D}'\mathbf{W}\mathbf{D})^{-1}\mathbf{D}'\mathbf{W}\mathbf{S}\mathbf{W}\mathbf{D}(\mathbf{D}'\mathbf{W}\mathbf{D})^{-1}/T$. To construct the standard errors for the alphas of individual portfolios, we use the variance–covariance matrix for $\mathbf{g}_T$, $\mathrm{var}(\mathbf{g}_T) = [\mathbf{I} - \mathbf{D}(\mathbf{D}'\mathbf{W}\mathbf{D})^{-1}\mathbf{D}'\mathbf{W}]\mathbf{S}[\mathbf{I} - \mathbf{D}(\mathbf{D}'\mathbf{W}\mathbf{D})^{-1}\mathbf{D}'\mathbf{W}]'/T$. Finally, we form a $\chi^2$ test on the null hypothesis that all the alphas are jointly zero, $\mathbf{g}_T'[\mathrm{var}(\mathbf{g}_T)]^{+}\mathbf{g}_T \sim \chi^2(\#\text{moments} - \#\text{parameters})$, in which $\chi^2$ is the chi-square distribution with the degrees of freedom given by the number of moments minus the number of parameters. The superscript $+$ denotes pseudo-inversion.

turn rebalanced monthly. The sample is from January 1972 to December 2012. The starting point is restricted by the availability of quarterly earnings data. Different from price momentum, our procedure for earnings momentum does not impose a one-month lag between the sorting period and the holding period, or excludes stocks with prices per share lower than $5 at the portfolio formation.

#### 3.2.2. Variable measurement

The capital stock, $K_{it}$, is net property, plant, and equipment (Compustat annual item PPENT). Investment, $I_{it}$, is capital expenditures (item CAPX) minus sales of property, plant, and equipment (item SPPE, set to zero if missing). The capital depreciation rate, $\delta_{it}$, is the amount of depreciation (item DP) divided by the capital stock. Output, $Y_{it}$, is sales (item SALE). Total debt, $B_{it+1}$, is long-term debt (item DLTT) plus short term debt (item DLC). Market leverage, $w_{it}$, is the ratio of total debt to the sum of total debt and market value of equity, which is the stock price at the fiscal yearend (item PRCC_F) times common shares outstanding (item CSHO). The tax rate, $\tau_t$, is the statutory corporate income tax rate from the Commerce Clearing House's annual publications. In the model time-$t$ stock variables are at the beginning of year $t$, and time-$t$ flow variables are over the course of year $t$. However, both stock and flow variables in Compustat are recorded at the end of the year. As such, for example, the year 2003 time-$t$ stock variables are taken from the 2002 balance sheet, and flow variables from the 2003 income or cash flow statement.

Firm-level corporate bond data are rather limited, and few or even none of the firms in several testing portfolios have corporate bond returns. To measure the pre-tax corporate bond returns in a broad sample, the procedure from Blume et al. (1998) is used to impute the credit ratings for firms with no crediting ratings data in Compustat. After the credit ratings are imputed, the corporate bond returns for a given credit rating are assigned to all the firms with the same credit rating.[5] The data on corporate bond returns by credit ratings are from Barclays U.S. aggregate corporate bond series via Datastream. Because the Barclays data start from August 1988, data from Ibbotson Associates are used prior to that date. Finally, equal-weighted corporate bond returns are computed across the firms in a given portfolio.

### 3.3. Timing alignment

Momentum portfolios are rebalanced monthly, but accounting variables in Compustat are annual. As such, aligning the timing of stock returns with that of investment returns is intricate. This measurement difficulty should, ex ante, go against any effort to identify fundamental forces behind momentum.[6]

Our work implements a more polished timing alignment procedure than Liu et al. (2009). In particular, monthly levered investment returns of a momentum portfolio are constructed from its annual accounting variables to match with the portfolio's monthly stock returns. Our procedure contains three steps. First, each month, the timing of firm-level characteristics at the sub-decile level is determined. The general principle is to take firm-level characteristics from the fiscal yearend that is closest to the month in question to measure economic variables dated time $t$ in the model, and to take characteristics from the subsequent fiscal yearend to measure variables dated $t+1$ in the model.

Fig. 1 illustrates the general principle for firms with December or June fiscal yearend. Firms with fiscal year ending in other months are handled analogously.[7] As noted, in Compustat stock variables are measured at the end of the fiscal year and flow variables are over the course of the fiscal year. As such, the investment return constructed from annual accounting variables goes roughly from the midpoint of the current fiscal year to the midpoint of the next fiscal year. For firms with December fiscal yearend, this midpoint time interval is from July of year $t$ to June of year $t+1$. For firms with June fiscal yearend, the time interval is from January to December of year $t$.

Panel A shows the timing alignment for firms with December fiscal yearend. Consider the first sub-decile of the loser decile in July of year $t$. This sub-decile's holding period is from February of year $t$ to July of year $t$. For firms in this sub-decile, the first five months (February–June) lie to the left of the applicable time interval. For these five months, accounting variables at the fiscal yearend of calendar year $t$ are used to measure economic variables dated $t+1$ in the model, and accounting variables at the fiscal yearend of $t-1$ are used to measure economic variables dated $t$ in the model. However, for the last month in the holding period (July), because the month is within the midpoint time interval, accounting variables at

[5] An ordered probit model for credit ratings is first estimated on firms with credit ratings data. The fitted value is used to calculate the cutoff value for each rating. For firms without credit ratings, their scores are computed with the coefficients from the ordered probit model, and their credit ratings are imputed by applying the cutoff values of different credit ratings. The corporate bond returns for a given credit rating are assigned to the firms with the same rating. The explanatory variables in the ordered probit model include: interest coverage, operating income after depreciation plus interest expense over interest expense; the operating margin, operating income before depreciation over sales; long-term leverage, long-term debt over assets; total leverage, long-term debt plus debt in current liabilities plus short-term borrowing over assets; the natural logarithm of the market value of equity deflated to 1973 by the consumer price index; as well as the market beta and residual volatility from the market regression estimated for each firm in each calendar year with at least 200 daily returns from CRSP. One leading and one lagged values of the market return are used to account for nonsynchronous trading.

[6] Quarterly Compustat data are explored but not used eventually. First, annual Compustat data provide a longer sample starting from 1963. In contrast, because of data availability of quarterly property, plant, and equipment, the quarterly sample can only start from 1977. Second, quarterly data display strong seasonality that affects the dynamics of momentum profits. A common way of controlling for seasonality is to average the quarterly observations within a given year. However, doing so is largely equivalent to using the annual data. Finally, the annual data are of higher quality because quarterly accounting statements are not legally required to be audited by an independent auditor.

[7] In our sample, the five most frequent months in which firms end their fiscal year are December (62.2%), June (8.1%), September (6.5%), March (5.5%), and January (3.7%).

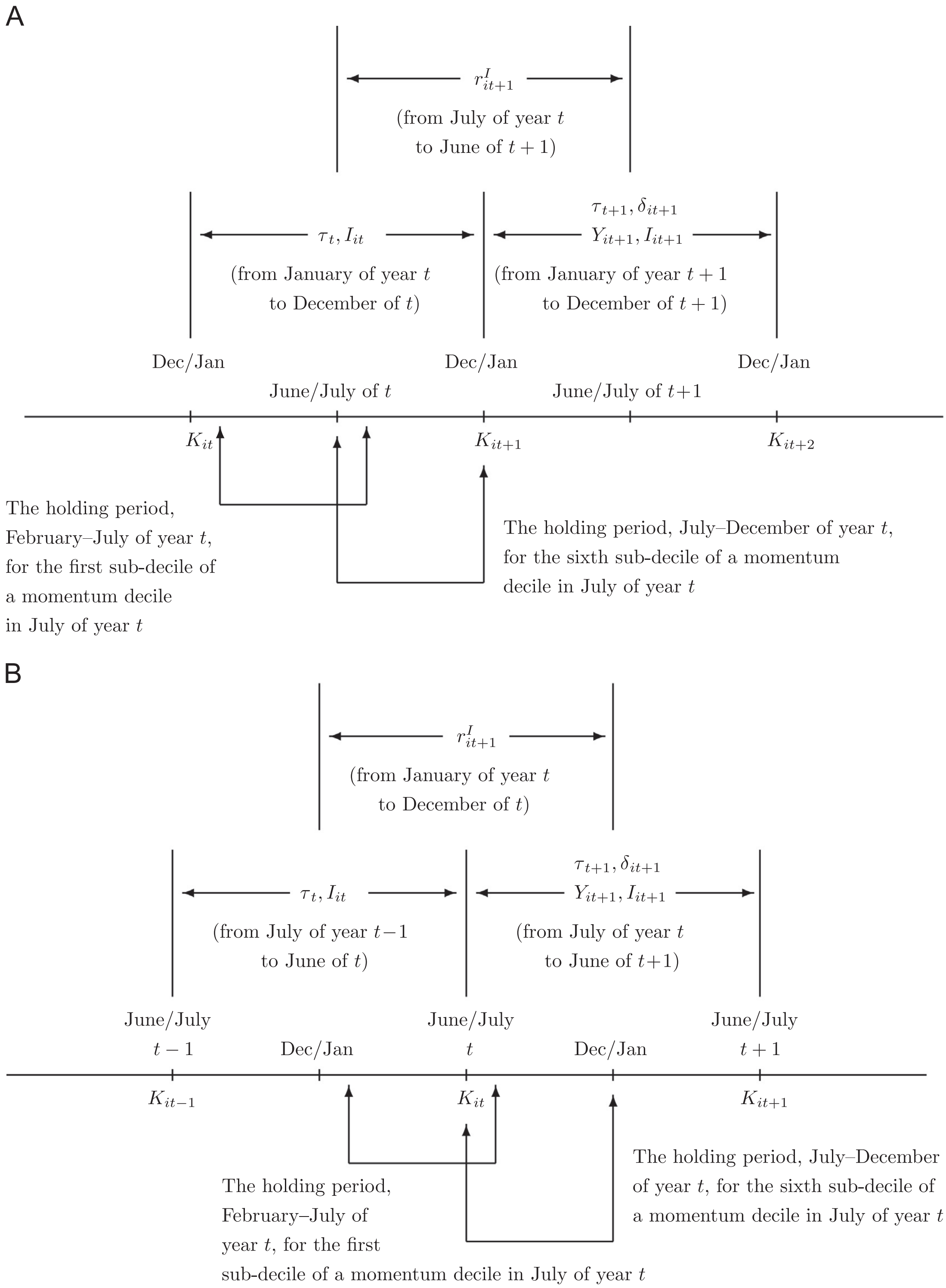


**Fig. 1.** Timing alignment between monthly stock returns and annual accounting variables from Compustat. *Note*: $r^I_{it+1}$ is the investment return of firm *i* constructed from characteristics from the current fiscal year and the next fiscal year. $\tau_t$ and $I_{it}$ are the corporate income tax rate and firm *i*'s investment for the current fiscal year, and $\delta_{it+1}$ and $Y_{it+1}$ are the depreciate rate and sales from the next fiscal year, respectively. $K_{it}$ is firm *i*'s capital observed at the end of the last fiscal year (or at the beginning of the current fiscal year). Panel A: Firms with December fiscal yearend and Panel B: Firms with June fiscal yearend.

the fiscal yearend of $t+1$ are used to measure economic variables dated $t+1$ in the model, and accounting variables at the fiscal yearend of $t$ are used to measure economic variables dated $t$ in the model. Panel B shows the timing alignment for firms with June fiscal yearend. Their applicable midpoint time interval is from January to December of year $t$. For those firms in the first sub-decile of the loser decile in July of year $t$, all the holding period months (February–July of year $t$) lie within the time interval. As such, accounting variables at the fiscal yearend of $t$ are used to measure economic variables dated $t$ in the model, and accounting variables at the fiscal yearend of $t+1$ are used to measure economic variables dated $t+1$ in the model.

The second step in our timing alignment procedure is to construct the components of the levered investment returns at the sub-decile level. For each month, characteristics for a given sub-decile are calculated by aggregating firm characteristics over the firms in the sub-decile. For example, the sub-decile investment-to-capital for month $t$, $I_{it}/K_{it}$, is the sum of investment for all the firms within the sub-portfolio in month $t$ divided by the sum of capital for the same set of firms in month $t$. Other components are aggregated analogously. Because the portfolio composition changes monthly, the sub-decile characteristics also change monthly.

The third and final step in our timing alignment procedure is to calculate the levered investment returns for a given decile. Continue to consider the loser decile. After obtaining its sub-decile characteristics, in each month the cross-sectional average characteristics are computed over the six sub-deciles to obtain the characteristics for the loser decile for each month. These characteristics are then used to construct the investment returns using Eq. (1). The investment returns are in annual terms but vary monthly because the sub-decile characteristics change monthly. Bond returns for a testing portfolio are constructed from firm-level corporate bond returns from the imputation procedure in the same way as portfolio stock returns are constructed. Finally, levered investment returns are calculated at the portfolio level using Eq. (2).

## 4. Empirical results

Section 4.1 studies average momentum profits. Section 4.2 investigates the reversal of momentum and the variation of momentum across market states. Section 4.3 examines the interaction of momentum with firm characteristics. Finally, Section 4.4 explores the issue of risk.

### *4.1. Average momentum profits*

From Panel A of Table 1, the average returns of the price momentum deciles increase monotonically from 4.04% per annum for the loser decile to 19.13% for the winner decile. The average return spread of 15.09% is more than six standard errors from zero. The Carhart (1997) alpha, calculated as the annualized alpha from monthly regressions of portfolio returns on the market, size, book-to-market, and momentum factors, of the winner-minus-loser decile is 6.51%, which is more than four standard errors from zero. The data for the Carhart factors are from Kenneth French's Web site. The average magnitude of the alphas is 1.10% in the Carhart model, and the model is strongly rejected by the Gibbons et al. (1989, GRS) test on the null hypothesis that all the ten alphas are jointly zero.

From Panel B, earnings momentum is weaker than price momentum. The average returns increase from 10.48% per annum for the loser decile to 18.95% for the winner decile. The spread of 8.47% is 5.82 standard errors from zero. The Carhart alpha of the winner-minus-loser decile is 7.25%, which is more than 4.5 standard errors from zero. The average magnitude of the alphas is 3.43% in the Carhart model, which is again rejected by the GRS test.

#### *4.1.1. Testing the investment model*

The investment model performs well overall. From Panel A of Table 1, the mean absolute error across the price momentum deciles is 0.83% per annum in the investment model. However, the model is still rejected with a $p$-value of 0.04 for the overidentification test. For the earnings momentum deciles, Panel B shows that the mean absolute error is 0.63%, and that the investment model cannot be rejected ($p$-value$=$0.09).

The investment model is parsimonious with only two parameters, the adjustment cost parameter, $a$, and the capital's share, $\kappa$. With the price momentum deciles, the $a$ estimate is 2.52 with a standard error (se) of 0.94, and the $\kappa$ estimate is 0.12 (se$=$0.02). With the earnings momentum deciles, $a$ is 5.41 (se$=$2.51), and $\kappa$ 0.17 (se$=$0.03). The estimates of the capital's share, which are significantly positive and between zero and one, make economic sense. Their magnitudes are somewhat lower than the typical value around 0.30 in quantitative macroeconomic studies (e.g., Prescott, 1986). However, our estimates are obtained from a microeconometric design based on stock returns data, a design different from the standard growth accounting based on aggregate quantities data. Browning et al. (1999), for instance, argue that typical parameter values adopted in quantitative macroeconomic studies can be inconsistent with microeconometric estimates, which in turn tend to vary a great deal depending on specific econometric design as well as sample.

The estimates of the adjustment cost parameter, $a$, are significantly positive, meaning that the adjustment cost function is increasing and convex in investment. The estimates also vary greatly in the existing literature. Bloom (2009), for example, surveys the available estimates that range from 0 to 20, depending on the model specification and the level of aggregation in a given study. Our estimates seem sensible.

Table 1 also reports individual alphas from the investment model, $\alpha_i^q$, in which the levered investment returns are constructed with the $a$ and $\kappa$ estimates from one-step GMM. The $t$-statistics testing that a given $\alpha_i^q$ equals zero are also reported, with standard errors calculated from one-stage GMM. For price momentum, Panel A shows that the individual alphas range from $-1.61$% per annum for the loser decile to 1.32% for the fifth decile. The winner-minus-loser alpha is 0.40%, which is about 0.1 standard errors from zero. For earnings momentum, Panel B shows that the investment alphas range from

**Table 1**
Deciles on price and earnings momentum, asset pricing tests, economic characteristics, and comparative statics on the investment model.

Panel A: price momentum

Descriptive statistics and the investment alphas

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ | mae | $p$-val |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $r_i^S$ | 4.04 | 8.74 | 10.50 | 11.54 | 12.36 | 13.10 | 13.28 | 14.88 | 16.42 | 19.13 | 15.09 | | |
| $\sigma_i^S$ | 26.55 | 21.85 | 20.17 | 19.19 | 18.83 | 18.81 | 19.28 | 20.46 | 22.54 | 27.41 | 16.68 | | |
| $\alpha_i$ | −4.18 | −1.49 | −0.60 | −0.15 | 0.06 | 0.28 | −0.40 | 0.51 | 1.00 | 2.34 | 6.51 | 1.10 | 0.00 |
| $t_{\alpha_i}$ | −3.30 | −1.84 | −0.87 | −0.22 | 0.09 | 0.47 | −0.72 | 0.86 | 1.31 | 1.74 | 4.22 | | |
| $\alpha_i^q$ | −1.61 | 0.60 | 0.87 | 0.94 | 1.32 | 0.65 | 0.06 | −0.40 | −0.60 | −1.21 | 0.40 | 0.83 | 0.04 |
| $t_{\alpha_i^q}$ | −0.39 | 0.16 | 0.26 | 0.30 | 0.44 | 0.22 | 0.02 | −0.13 | −0.19 | −0.29 | 0.12 | | |

Components of the levered investment return

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ | $[t]$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_{it}/K_{it}$ | 0.22 | 0.21 | 0.20 | 0.19 | 0.19 | 0.20 | 0.20 | 0.21 | 0.22 | 0.25 | 0.04 | 3.60 |
| $\frac{I_{it+1}/K_{it+1}}{I_{it}/K_{it}}$ | 0.83 | 0.92 | 0.95 | 0.98 | 0.99 | 1.02 | 1.03 | 1.07 | 1.09 | 1.15 | 0.32 | 15.37 |
| $Y_{it+1}/K_{it+1}$ | 3.16 | 3.02 | 3.01 | 3.00 | 3.00 | 3.13 | 3.19 | 3.39 | 3.59 | 4.10 | 0.94 | 5.56 |
| $w_{it}$ | 0.34 | 0.29 | 0.27 | 0.25 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.22 | −0.12 | −7.16 |
| $\delta_{it+1}$ | 0.14 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.14 | 0.14 | 0.17 | 0.03 | 1.91 |
| $r_{it+1}^B$ | 0.64 | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 | 0.64 | 0.00 | 0.16 |

The investment alphas, $\alpha_i^q$, from comparative statics

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\overline{I_{it}/K_{it}}$ | −2.58 | 0.92 | 2.34 | 3.32 | 3.77 | 2.62 | 1.40 | −0.13 | −2.47 | −7.23 | −4.65 |
| $\overline{q_{it+1}/q_{it}}$ | −7.26 | −1.84 | −0.64 | 0.20 | 1.00 | 1.05 | 0.80 | 1.24 | 1.69 | 2.66 | 9.92 |
| $\overline{Y_{it+1}/K_{it+1}}$ | −2.59 | −1.13 | −0.95 | −0.98 | −0.56 | −0.35 | −0.54 | 0.49 | 1.52 | 4.13 | 6.73 |
| $\overline{w_{it}}$ | −1.39 | 0.45 | 0.94 | 0.84 | 1.22 | 0.48 | −0.01 | −0.76 | −0.99 | −1.48 | −0.09 |

Panel B: earnings momentum

Descriptive statistics and the investment alphas

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ | mae | $p$-val |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $r_i^S$ | 10.48 | 10.69 | 12.44 | 13.49 | 15.48 | 16.20 | 17.91 | 17.91 | 19.07 | 18.95 | 8.47 | | |
| $\sigma_i^S$ | 24.35 | 22.78 | 23.18 | 23.54 | 22.95 | 22.56 | 22.22 | 21.84 | 22.06 | 21.15 | 9.24 | | |
| $\alpha_i$ | −0.28 | −0.49 | 0.57 | 1.82 | 3.29 | 3.69 | 5.24 | 5.46 | 6.54 | 6.98 | 7.25 | 3.43 | 0.00 |
| $t_{\alpha_i}$ | −0.16 | −0.37 | 0.47 | 1.23 | 2.51 | 3.37 | 4.78 | 5.29 | 5.24 | 6.16 | 4.55 | | |
| $\alpha_i^q$ | −0.39 | −0.71 | 0.34 | 0.20 | 1.05 | 0.33 | 0.78 | −0.73 | 0.44 | −1.31 | −0.92 | 0.63 | 0.09 |
| $t_{\alpha_i^q}$ | −0.09 | −0.18 | 0.09 | 0.05 | 0.25 | 0.08 | 0.20 | −0.20 | 0.12 | −0.37 | −0.36 | | |

Components of the levered investment return

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ | $[t]$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_{it}/K_{it}$ | 0.19 | 0.20 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.20 | 0.01 | 2.18 |
| $\frac{I_{it+1}/K_{it+1}}{I_{it}/K_{it}}$ | 0.95 | 0.95 | 0.97 | 0.98 | 1.00 | 1.01 | 1.02 | 1.05 | 1.05 | 1.05 | 0.10 | 4.96 |
| $Y_{it+1}/K_{it+1}$ | 3.01 | 2.97 | 2.91 | 2.97 | 3.06 | 3.16 | 3.25 | 3.22 | 3.18 | 3.53 | 0.52 | 3.66 |
| $w_{it}$ | 0.29 | 0.27 | 0.29 | 0.28 | 0.28 | 0.25 | 0.25 | 0.25 | 0.24 | 0.20 | −0.09 | −7.45 |
| $\delta_{it+1}$ | 0.14 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.00 | −0.68 |
| $r^B_{it+1}$ | 0.72 | 0.72 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.72 | 0.00 | 0.11 |

The investment alphas, $\alpha^q_i$, from comparative statics

| | $L$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $W$ | $W-L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\overline{I_{it}/K_{it}}$ | 0.62 | −1.82 | 0.17 | 1.84 | 2.89 | 0.95 | 0.86 | 0.19 | 0.53 | −4.54 | −5.16 |
| $\overline{q_{it+1}/q_{it}}$ | −3.20 | −3.42 | −1.53 | −0.95 | 0.88 | 0.84 | 1.45 | 1.40 | 2.71 | 0.88 | 4.07 |
| $\overline{Y_{it+1}/K_{it+1}}$ | −1.65 | −2.13 | −1.55 | −1.25 | 0.24 | 0.55 | 1.69 | −0.07 | 0.85 | 1.71 | 3.36 |
| $\overline{w}_{it}$ | −0.57 | −0.70 | 0.84 | 0.55 | 1.20 | 0.02 | 0.62 | −0.98 | 0.18 | −2.52 | −1.95 |

*Note*: For each decile, the table reports (in annual percent) average stock return, $r^S_i$, stock return volatility, $\sigma^S_i$, the alpha from monthly Carhart (1997) four-factor regressions, $\alpha_i$, and their $t$-statistics adjusted for heteroscedasticity and autocorrelations. $\alpha^q_i$ is the alpha from the investment model, calculated as $E_T[r^S_{it+1}-r^{Iw}_{it+1}]$, in which $E_T$ is the sample mean, and $r^{Iw}_{it+1}$ is the levered investment return. "mae" is the mean absolute error. The $p$-value ($p$-val) for the Carhart model is from the GRS test of the null that the Carhart alphas across the ten deciles are jointly zero. The $p$-value for the investment model is from the overidentification test that the investment alphas across the deciles are jointly zero. Panel B reports average characteristics for each decile including current-period investment-to-capital, $I_{it}/K_{it}$; the growth rate of investment-to-capital, $(I_{it+1}/K_{it+1})/(I_{it}/K_{it})$; next-period sales-to-capital, $Y_{it+1}/K_{it+1}$; market leverage, $w_{it}$; the next-period rate of depreciation, $\delta_{it+1}$; and the corporate bond returns in annualized percent, $r^B_{it+1}$. Panel C reports four comparative static experiments on the investment model: $\overline{I_{it}/K_{it}}$, $\overline{q_{it+1}/q_{it}}$, $\overline{Y_{it+1}/K_{it+1}}$, and $\overline{w}_{it}$, in which $q_{it+1}/q_{it}=[1+(1-\tau_{t+1})a(I_{it+1}/K_{it+1})]/[1+(1-\tau_t)a(I_{it}/K_{it})]$. In the experiment denoted $\overline{Y_{it+1}/K_{it+1}}$, $Y_{it+1}/K_{it+1}$ is set to be its cross-sectional average in year $t+1$ across all the deciles. The parameters from one-stage GMM are used to reconstruct the levered investment returns, with all the other characteristics unchanged. The other three experiments are designed analogously. The model error is then the average difference between stock returns and reconstructed levered investment returns. $L$ is the loser, $W$ the winner, and $W-L$ the winner-minus-loser decile.

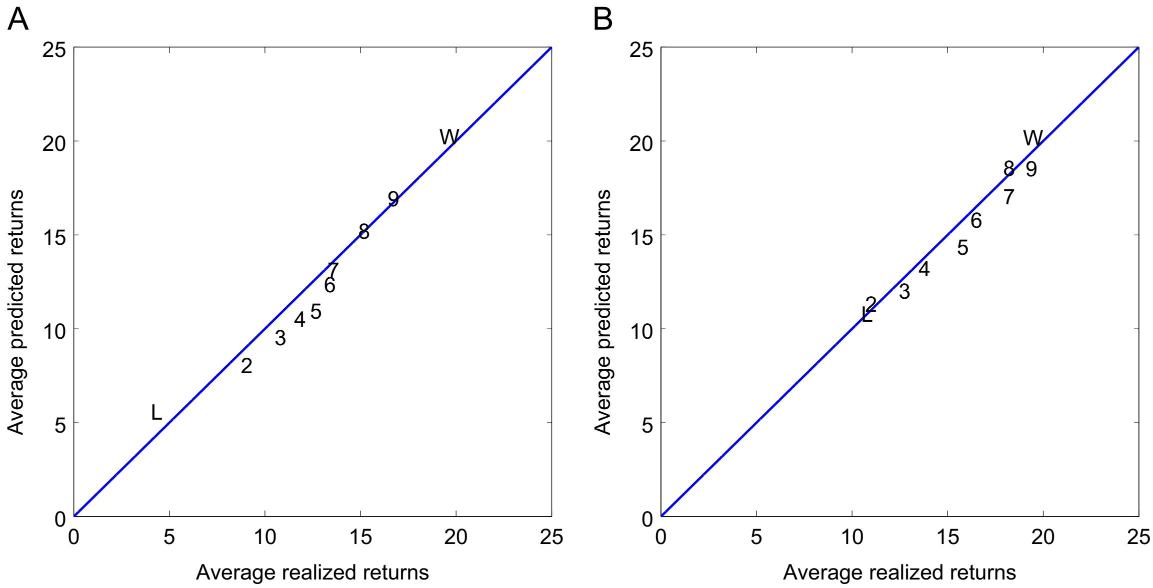


**Fig. 2.** Average predicted stock returns from the investment model versus average realized stock returns, deciles on price and earnings momentum. *Note*: The average predicted stock returns are given by $E_T[r^{lw}_{it+1}]$, in which $E_T$ is the sample mean, and $r^{lw}_{it+1}$ is levered investment returns. The parameter estimates from one-stage GMM are used to construct the levered investment returns. The average returns are in annual percent. The deciles are formed in the ascending order. *L* is the loser decile, and *W* the winner decile. Panel A: Price momentum and Panel B: Earnings momentum.

$-1.31\%$ per annum for the winner decile to 1.05% for the fifth decile. The winner-minus-loser alpha is $-0.92\%$, which is within 0.4 standard errors of zero. Finally, Fig. 2 plots the average levered investment returns of the testing deciles from the investment model against their average realized stock returns. If the model's performance is perfect, all the observations should lie exactly on the 45-degree line. The scatter plots are closely aligned with the 45-degree line, indicating an overall good fit of the model.

### *4.1.2. Accounting for average momentum profits*

What are the economic mechanisms via which the investment model matches momentum profits? Eqs. (1) and (2) identify several components of expected levered investment returns. The time series average of each component for each testing portfolio is examined. For the growth rate of $q$, defined as $q_{it} \equiv 1+(1-\tau_t)a(I_{it}/K_{it})$, because it involves the unobserved adjustment cost parameter, $a$, the average growth rate of investment-to-capital $(I_{it+1}/K_{it+1})/(I_{it}/K_{it})$ is computed instead. From Panel A of Table 1, the price momentum winner decile has a higher average gross growth rate of investment-to-capital than the price momentum loser decile: 1.15 versus 0.83. The winner decile also has a higher next-period sales-to-capital than the loser decile: 4.10 versus 3.16. Both components go in the right direction to capture average momentum profits. However, going in the wrong direction, the winner decile has a higher current-period investment-to-capital, 0.25 versus 0.22, and a lower market leverage, 0.22 versus 0.34, than the loser decile. Finally, the averages of the depreciate rate and the after-tax corporate bond return are largely flat across the price momentum deciles.[8]

Panel B reports the time series averages of expected return components across the earnings momentum deciles. The winner decile has a higher average growth rate of investment-to-capital, 1.05 versus 0.95 per annum, and a higher next-period sales-to-capital, 3.53 versus 3.01, than the loser decile. Both go in the right direction to capture average momentum profits.[9] Going in the wrong direction, the winner decile has a slightly higher current-period investment-to-capital, 0.20 versus 0.19, and a lower market leverage, 0.20 versus 0.29, than the loser decile. The averages of the depreciate rate and the after-tax corporate bond return are again flat. As such, the cross-sectional patterns of the components across the earnings momentum deciles are similar but weaker than those across the price momentum deciles. The evidence is consistent with earnings momentum being weaker than price momentum.

[8] The evidence that the average corporate bond returns are flat across the momentum deciles contrasts with Gebhardt et al. (2005), who show that stock momentum spills over to corporate bond returns. Our evidence differs for several reasons. First, Gebhardt et al. use a small sample from the Lehman Brothers Fixed Income Database, which is substantially smaller in the coverage of the cross section than the CRSP-Compustat universe. Second, Gebhardt et al. consider only investment grade corporate bonds, while our work uses both investment grade and non-investment grade credit ratings. Finally, to study the broader cross section in the CRSP-Compustat universe, our work follows Blume et al. (1998) to assign the corporate bond returns for a given credit rating to all the firms with the same credit rating. This procedure likely restricts the cross-sectional variation in average corporate bond returns.

[9] This evidence is consistent with the theoretical predictions in Li (2014). Working with a simulated dynamic investment model, Li argues that winners are more profitable than losers because of recent positive productivity shocks to winners and recent negative productivity shocks to losers. In response, winners commit to higher investment and losers to lower investment (and even disinvestment) in the near future.

Comparative statics can quantify the role of the expected return components in accounting for price and earnings momentum. A given component is set to its cross-sectional average in each month at the decile level. The $a$ and $\kappa$ estimates are then used to reconstruct levered investment returns, with all the other components unchanged, and the resulting changes in the alphas are examined. A large change in magnitude would indicate that the component in question is quantitatively important for the model's performance.

The comparative statics show that the growth rate of marginal $q$ is the most important, and sales-to-capital is the second most important source of momentum profits. From Panel A of Table 1, for price momentum, without the cross-sectional variation in the growth rate of $q$, the winner-minus-loser alpha jumps to 9.92% per annum. Without the cross-sectional variation in sales-to-capital, this alpha jumps to 6.73%. In contrast, the alpha is only 0.40% in the benchmark estimation. For earnings momentum, Panel B shows that without the cross-sectional variation in the growth rate of $q$, the winner-minus-loser alpha jumps to 4.07%. Without the cross-sectional variation in sales-to-capital, the alpha becomes 3.36%. In contrast, this alpha is only $-0.92$% in the benchmark estimation.

### 4.2. *The dynamics of momentum*

Only average momentum profits have been examined so far. However, a few stylized facts involve their dynamics. The dynamics are particularly intriguing because the model parameters are estimated from matching only average momentum profits. As such, the dynamics of momentum can serve as separate diagnostics on the model's performance.

#### 4.2.1. *Reversal of momentum profits in long horizons*

Chan et al. (1996) show that momentum is short-lived. In particular, momentum profits are large and positive up to the one-year horizon but turn negative afterward. Fig. 3 reports the event-time evolution during 36 months after the portfolio formation for the average stock return as well as the averages of the levered investment return and its key components for the winner and the loser deciles. Panel A replicates the reversal of price momentum in our sample. The average winner-minus-loser return starts at 19.98% per annum in the first month in the holding period, falls to 13.15% in month six, converges largely to zero in month ten, and turns negative afterward.

The investment model largely reproduces this reversal. From Panel B, the levered investment return for the winner-minus-loser decile starts at 18.21% per annum in the first month, falls to 10.73% in month six, and further to 2.87% in month twelve. The predicted price momentum converges largely to zero in month fifteen and turns negative afterward. As such, price momentum takes somewhat longer to revert to zero in the model than in the data.[10] Panel C shows similar dynamics for the unlevered investment return.

More important, it is the expected growth component that captures the short-lived nature of price momentum. Measuring the expected growth as the average growth of marginal $q$, Panel D shows that the winner-minus-loser spread starts at 9.97% in month one, weakens to 5.90% in month six, and converges largely to zero in month twelve. From Panel E, the investment-to-capital growth spread displays a similar pattern. The spread starts at 39.45% in month one, weakens to 23.06% in month six, converges to zero in month thirteen, and turns negative afterward. In contrast, Panel F shows that the sales-to-capital spread is more persistent. Starting at 1.03 in month one, the sales-to-capital spread drops to 0.80 at the one-year horizon but remains high at 0.59 at the two-year horizon and 0.37 at the third-year horizon.

The remaining panels in Fig. 3 document the dynamics for earnings momentum. From Panel G, the average winner-minus-loser return starts at 17.85% per annum in month one, falls to 3.36% in month six, converges to zero in month eight, and turns negative afterward. The winner-minus-loser spread in the levered investment return starts at 12.06% in month one, weakens to 6.12% in month six and further to 1.54% in month twelve, and converges to zero in month sixteen. As such, earnings momentum also takes longer to revert in the model than in the data.[11] From Panels J and K, the expected growth component is again responsible for the reversal. In contrast, the sales-to-capital spread is more persistent.

Relatedly, Bernard and Thomas (1989) show that a disproportionately large amount of earnings momentum occurs within five days of earnings announcements. Jegadeesh and Titman (1993) document that the average three-day returns around quarterly earnings announcement dates represent about 25% of momentum for the first six-month holding period. The announcement returns also display reversal in long horizons. Unfortunately, this pattern cannot be reproduced because daily data on characteristics are not available. However, Eq. (2) implies that levered investment returns should equal stock returns in realization, state by state and period by period. As such, it is not inconceivable that the ex post pattern of daily investment returns would mimic that of daily stock returns. Intuitively, positive earnings shocks at $t+1$ would increase the marginal product of capital at $t+1$, and increase the investment returns from $t$ to $t+1$. The positive earnings shocks should also increase the investment-to-capital growth from $t$ to

[10] Average buy-and-hold returns over different horizons after the portfolio formation are also calculated (untabulated). The winner-minus-loser stock return is on average 7.98% over the six-month horizon, 9.19% over the first year but turns negative at $-6.49$% over the second year and $-5.16$% over the third year. The buy-and-holding levered investment returns are comparable in the model, 7.37% over the first six months, 10.43% over the first year, $-1.29$% over the second year, and $-4.34$% over the third year. The average returns are in semi-annual percent at the six-month horizon but in annual percent at the other horizons.

[11] For buy-and-hold returns, the earnings momentum winner-minus-loser stock return is on average 4.18% over the six-month horizon, 2.81% over the first year, and turns negative at $-2.32$% over the second year and $-2.43$% over the third year. The buy-and-holding returns are again comparable in the model: 4.60% over the first six months, 6.18% over the first year, $-0.37$% over the second year, and $-2.03$% over the third year.

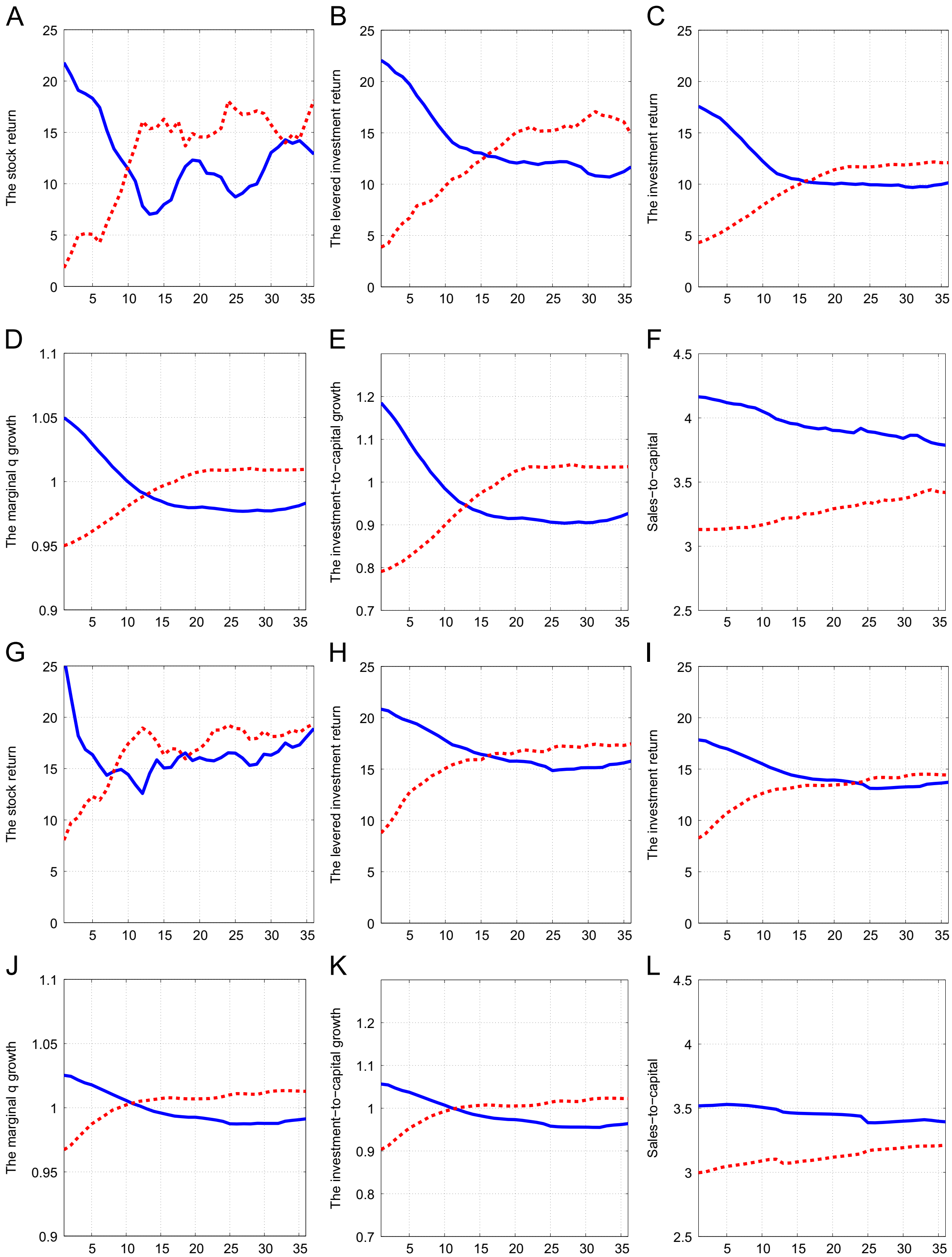


**Fig. 3.** Event-time evolution, price and earnings momentum. *Note*: For 36 months after the portfolio formation, this figure plots event-time evolution of the averages of the stock return, the levered investment return, the investment return, as well as the key components of the investment return for the winner (blue solid lines) and the loser deciles (red broken lines). The average returns are in annual percent. $R^6$ denotes price momentum and SUE earnings momentum. Panel A: The stock return, $R^6$, Panel B: The levered investment return, $R^6$, Panel C: The investment return, $R^6$, Panel D: The marginal q growth, $R^6$, Panel E: The investment-to-capital growth, $R^6$, Panel F: Sales-to-capital, $R^6$, Panel G: The stock return, SUE, Panel H: The levered investment return, SUE, Panel I: The investment return, SUE, Panel J: The marginal q growth, SUE, Panel K: The investment-to-capital growth, SUE and Panel L: Sales-to-capital, SUE. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

$t+1$ because investment increases with the marginal product of capital. As such, stock returns should move, immediately, in the same direction as earnings shocks. More important, because of the low persistence of the expected investment-to-capital growth, the investment returns around earnings announcement dates should also inherit the reversal of announcement date stock returns.

### *4.2.2. Market states and momentum profits*

Cooper et al. (2004) show that for price momentum, the average winner-minus-loser return during the six-month period after the portfolio formation is 0.93% per month following non-negative prior 36-month market returns (UP markets), but is −0.37% following negative prior 36-month market returns (DOWN markets).

The first six rows in Table 2 replicate this evidence for price momentum in our sample. If the UP and DOWN markets are categorized based on the value-weighted CRSP index returns over the prior 12-month period, the winner-minus-loser return over the six-month period after the portfolio formation is on average 9.89% following the UP markets, but 2.21% following the DOWN markets. Over the 12-month period after the portfolio formation, the winner-minus-loser return is on average 12.01% following the UP markets but 0.33% following the DOWN markets. This pattern also holds for earnings momentum. If the UP and DOWN markets are based on the value-weighted CRSP index returns over the prior 36-month period, the winner-minus-loser return over the six-month period after the portfolio formation is on average 5.76% following the UP markets but −4.76% following the DOWN markets. Over the 12-month period, the winner-minus-loser return is on average 5.57% following the UP markets but −12.96% following the DOWN markets.

The investment model fails to reproduce the procyclicality of momentum. From rows 7 to 12 in Table 2, if anything, the model predicts that price momentum is stronger in DOWN markets. In particular, based on prior 12-month market returns, the predicted winner-minus-loser return over the 12-month period after portfolio formation is 9.13% following the UP markets but 15.06% following the DOWN markets. Also, based on prior 36-month market returns, the predicted earnings momentum profits over the six-month horizon are 4.05% after the UP markets but 7.71% after the DOWN markets. This counterfactual prediction disappears if the market states are based on prior 12-month market returns, with 4.64% following the UP markets but 4.50% following the DOWN markets. However, the procyclicality is far weaker than that in the data.

Lettau and Ludvigson (2002) argue that time lags between investment decision and actual investment expenditure can temporally shift the correlation between investment returns and stock returns. Although the contemporaneous correlation is negative, the correlation between lagged stock returns and current investment returns is positive. However, the temporal shift in the correlation structure cannot explain the model's failure in capturing the procyclicality of momentum, as shown in the last six rows of Table 2.

**Table 2**
Market states and price and earnings momentum.

| State | $N$ | Returns | Panel A: months 1–6 | | | | Panel B: months 1–12 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $R^6$ | $[t]$ | SUE | $[t]$ | $R^6$ | $[t]$ | SUE | $[t]$ |
| DOWN | 36 | $r^S$ | −3.36 | −0.83 | −4.76 | −1.20 | −9.17 | −1.52 | −12.96 | −2.28 |
| DOWN | 24 | $r^S$ | −1.67 | −0.42 | −2.60 | −0.60 | −5.61 | −0.82 | −10.56 | −1.59 |
| DOWN | 12 | $r^S$ | 2.21 | 0.62 | 1.31 | 0.40 | 0.33 | 0.05 | −4.92 | −0.90 |
| UP | 36 | $r^S$ | 9.95 | 8.97 | 5.76 | 9.59 | 12.25 | 5.73 | 5.57 | 4.50 |
| UP | 24 | $r^S$ | 9.77 | 8.81 | 5.41 | 8.60 | 11.82 | 5.54 | 5.22 | 4.26 |
| UP | 12 | $r^S$ | 9.89 | 8.51 | 5.04 | 6.73 | 12.01 | 5.35 | 5.12 | 3.87 |
| DOWN | 36 | $r^{Iw}$ | 7.52 | 3.94 | 7.71 | 7.21 | 11.28 | 3.38 | 10.60 | 3.88 |
| DOWN | 24 | $r^{Iw}$ | 9.29 | 4.05 | 8.48 | 6.28 | 14.46 | 3.60 | 11.62 | 3.41 |
| DOWN | 12 | $r^{Iw}$ | 9.19 | 3.69 | 4.50 | 2.46 | 15.06 | 3.73 | 5.44 | 1.50 |
| UP | 36 | $r^{Iw}$ | 7.40 | 5.43 | 4.05 | 4.98 | 10.41 | 4.12 | 5.52 | 3.93 |
| UP | 24 | $r^{Iw}$ | 7.09 | 5.30 | 3.89 | 5.06 | 9.85 | 3.99 | 5.30 | 3.98 |
| UP | 12 | $r^{Iw}$ | 6.87 | 5.31 | 4.64 | 6.51 | 9.13 | 3.64 | 6.55 | 5.26 |
| DOWN | 36 | $r^{Iw}_{[+6]}$ | 6.23 | 2.98 | 6.71 | 5.13 | 10.95 | 2.81 | 10.26 | 3.48 |
| DOWN | 24 | $r^{Iw}_{[+6]}$ | 7.58 | 3.53 | 7.69 | 6.21 | 12.91 | 3.26 | 11.42 | 3.67 |
| DOWN | 12 | $r^{Iw}_{[+6]}$ | 11.01 | 5.32 | 6.11 | 4.14 | 18.18 | 5.37 | 8.18 | 2.72 |
| UP | 36 | $r^{Iw}_{[+6]}$ | 7.70 | 5.74 | 4.14 | 5.01 | 10.68 | 4.25 | 5.37 | 3.72 |
| UP | 24 | $r^{Iw}_{[+6]}$ | 7.48 | 5.58 | 3.94 | 4.94 | 10.34 | 4.11 | 5.12 | 3.72 |
| UP | 12 | $r^{Iw}_{[+6]}$ | 6.41 | 4.83 | 4.04 | 5.50 | 8.41 | 3.36 | 5.47 | 4.07 |

*Note*: At the end of each month $t$, all NYSE, AMEX, and NASDAQ firms are sorted into deciles based on their prior six-month returns from $t-5$ to $t-1$, denoted $R^6$, skipping month $t$. Stocks with prices per share under $5 at month $t$ are excluded. Separately, at the beginning of each month $t$, all stocks are sorted into deciles based on the SUE calculated with the most recently announced earnings. The average returns of the winner-minus-loser decile are cumulated across two holding periods: month $t+1$ to $t+6$ (Panel A) and month $t+1$ to $t+12$ (Panel B). Month $t$ is categorized as UP (DOWN) markets if the value-weighted CRSP index returns over months $t-N$ to $t-1$ with $N=36, 24$, or 12 are nonnegative (negative). The average returns are in semi-annual percent in Panel A and in annual percent in Panel B. The table reports average stock returns, $r^S$, average contemporaneous levered investment returns, $r^{Iw}$, and average six-month leading levered investment returns, $r^{Iw}_{[+6]}$.

### 4.3. The interaction of momentum with firm characteristics

The existing literature has also documented stylized facts on the interaction of momentum with firm characteristics, such as size, firm age, trading volume, credit ratings, stock return volatility, and book-to-market (see footnote 2). With two-way momentum portfolios as testing assets, the model's performance deteriorates relative to the benchmark estimation with the momentum deciles. However, although sometimes large, the investment alphas do not vary systematically with price or earnings momentum.

#### 4.3.1. Two-way momentum portfolios

Size is market capitalization at the end of the portfolio formation month $t$. Firms must have positive market capitalization to be included in the sample. Firm age is the number of months elapsed between the month when a firm first appears in the monthly CRSP database and the portfolio formation month $t$. Trading volume is the average daily turnover during the past six months from $t-6$ to $t-1$, in which daily turnover is the ratio of the number of shares traded each day to the number of shares outstanding at the end of the day.[12] Credit ratings in Compustat start only in 1985, and more than 50% of the firms have missing data. Using the Blume et al. (1998) imputation procedure provides us with a broad sample (see Section 3.2.2). Because the imputation requires annual accounting data, the imputed credit ratings are based on the accounting information at the fiscal yearend from at least six months ago. Stock return volatility is the standard deviation of weekly excess returns over the past six months from $t-6$ to $t-1$ as in Lim (2001).[13] To calculate book-to-market equity, the market equity is at the most recent month from CRSP, and the book equity is common equity (Compustat annual item CEQ) plus balance sheet deferred tax (item TXDB, zero if missing) at the fiscal yearend from at least six months ago.

To form two-way (three-by-three) portfolios from interacting price momentum with, for instance, stock return volatility, stocks are sorted into terciles at the end of each month $t$ on the stock return volatility calculated at the end of the month, and independently on prior six-month returns from $t-6$ to $t-1$. From taking interactions, nine volatility and price momentum portfolios are formed. The resulting portfolios for the subsequent six months are held from month $t+1$ to $t+6$ (skipping month $t$), and all stocks are equal-weighted within a given portfolio. Stocks with prices per share less than $5 at the portfolio formation are again excluded. To form two-way portfolios from interacting earnings momentum with stock return volatility, stocks are sorted into terciles at the end of each month $t$ on the stock return volatility calculated at the end of the month, and independently on the earnings surprises calculated with the most recently announced earnings. Taking intersections forms nine portfolios. The equal-weighted monthly portfolio returns are computed from month $t+1$ to $t+6$, and the portfolios are rebalanced monthly.[14]

#### 4.3.2. Parameter estimates and the overidentification test

Table 3 reports the point estimates and the overidentification tests with the two-way momentum portfolios. For price momentum, Panel A shows that the estimates of the adjustment cost parameter, $a$, ranging from 1.97 to 3.44, are close to 2.52 from the benchmark estimation with the one-way deciles. Also, the standard errors range from 0.70 to 0.95, meaning that the $a$ estimates are all significantly positive. The estimates of the capital's share, $\kappa$, ranging from 0.09 and 0.13, are also close to 0.12 from the benchmark estimation, and are also precise. For earnings momentum, Panel B shows that the $a$ estimates, ranging from 1.14 to 7.20, encompass the estimate of 5.41 from the benchmark estimation. Most estimates are significantly positive. The $\kappa$ estimates, ranging from 0.09 to 0.16, are also precise.

The model's overall performance deteriorates somewhat relative to the benchmark estimation with deciles. First, the model is rejected by the overidentification test across all sets of the price momentum portfolios and all but one set of the earnings momentum portfolios. This evidence is a testimony to the statistical power of our test. The power stems from our more polished timing alignment procedure, which allows us to construct monthly levered investment returns to match with monthly stock returns. Second, the mean absolute errors from the two-way portfolios are universally larger than those from the deciles. In particular, the mean absolute error from the price momentum deciles is 0.83% per annum, which amounts to 6.69% of the average return across the deciles, 12.4%. In contrast, the mean absolute errors from the size-price momentum and the book-to-market and price momentum portfolios are 3.66% and 3.10%, which are about 29.37% and 25.15% of the average returns across the testing portfolios, 12.46% and 12.33%, respectively.

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[12] As in Lee and Swaminathan (2000), our sample is restricted to include only NYSE and AMEX stocks when forming the trading volume and momentum portfolios (the number of shares traded for Nasdaq stocks is inflated relative to NYSE and AMEX stocks because of double counting of dealer trades).

[13] Weekly returns are from Thursday to Wednesday to mitigate bid-ask effects in daily prices. Excess returns are calculated as raw weekly returns minus weekly risk-free rates. The daily risk-free rates (available after July 1, 1964) are from Kenneth French's Web site. For days prior to that date, the monthly rate for a given month divided by the number of trading days within the month is used as daily rates. A stock is required to have at least 20 weeks of data to enter the sample.

[14] For credit ratings, stocks are sorted into three categories in each month based on their imputed credit ratings calculated with accounting information at the fiscal yearend from at least six months ago. The high category contains firms with credit ratings of AAA, AA, and A, the median with the BBB rating, and the low category with ratings lower than BBB. As in Avramov et al. (2007), sequential sorts are used by first grouping stocks into three ratings categories and then splitting each category into three momentum terciles. Independent sorts are used in all the other two-way portfolios.

**Table 3**
Parameter estimates and tests of overidentification, two-way momentum portfolios.

| | Panel A: price momentum | | | | | | | Panel B: earnings momentum | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Deciles | Size | Age | Trading volume | Credit ratings | Stock return volatility | Book-to-market | Deciles | Size | Age | Trading volume | Credit ratings | Stock return volatility | Book-to-market |
| $a$ | 2.52 | 2.33 | 2.37 | 2.76 | 1.97 | 3.17 | 3.44 | 5.41 | 2.74 | 2.75 | 2.56 | 1.14 | 2.74 | 7.20 |
| [se] | 0.94 | 0.70 | 0.95 | 0.93 | 0.83 | 0.82 | 0.89 | 2.51 | 0.60 | 1.55 | 1.32 | 0.72 | 0.76 | 2.36 |
| $\kappa$ | 0.12 | 0.09 | 0.12 | 0.12 | 0.12 | 0.12 | 0.13 | 0.17 | 0.09 | 0.12 | 0.12 | 0.11 | 0.12 | 0.16 |
| [se] | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 |
| $\chi^2$ | 16.17 | 94.41 | 59.98 | 33.89 | 35.94 | 42.11 | 69.07 | 13.78 | 168.85 | 8.76 | 62.34 | 28.48 | 22.39 | 18.01 |
| d.f. | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 7 | 7 | 7 | 7 | 7 | 7 |
| $p$-val | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.27 | 0.00 | 0.00 | 0.00 | 0.01 |
| mae | 0.83 | 3.66 | 1.29 | 1.67 | 1.68 | 1.92 | 3.10 | 0.63 | 4.37 | 1.08 | 2.30 | 1.35 | 1.95 | 2.88 |

*Note*: Results are from one-stage GMM with an identity weighting matrix. $a$ is the adjustment cost parameter and $\kappa$ is the capital's share. The standard errors, denoted "se," are beneath the point estimates. $\chi^2$, d.f., and $p$-val are the statistic, the degrees of freedom, and the $p$-value testing that the expected return errors across a given set of testing assets are jointly zero (the overidentification test). "mae" is the mean absolute error in annualized percent for a given set of testing portfolios from the investment model. The testing portfolios are two-way (three-by-three) portfolios from interacting price or earnings momentum with a given characteristic. For comparison, the table also includes the results from the benchmark estimation with deciles.

#### 4.3.3. *Individual alphas*

Fig. 4 plots average predicted stock returns from the investment model against average realized stock returns in the data. Although alphas can occasionally be large, the scatter points are mostly aligned with the 45-degree line. The evidence suggests that the investment model goes a long way in accounting for the interaction of momentum with firm characteristics. For instance, across the nine size-price momentum portfolios (Panel A), the individual alphas range from −3.63% to 6.95% per annum, which are not small. However, the winner-minus-loser alphas across the small, median, and big terciles are 0.19%, −2.69%, and −0.64%, respectively, which do not vary with size. In contrast, the average winner-minus-loser returns are 10.86%, 8.45%, and 6.67% across the size terciles, meaning that price momentum varies inversely with size. Across the nine size-earnings momentum portfolios (Panel G), the alphas range from −6.46% to 8.29%, which are large. However, the winner-minus-loser alphas across the size terciles are 1.75%, −3.21%, and −2.71%, respectively. In contrast, the average winner-minus-loser returns are 13.70%, 5.77%, and 2.16% across the size terciles, indicating a strong inverse relation between earnings momentum and size.

Asness (1997) and Asness et al. (2013) argue that book-to-market and momentum are negatively correlated, yet each forecasts stock returns with a positive slope. Both studies emphasize the importance of understanding this evidence. The investment model provides a coherent interpretation, at least conceptually. From Liu et al. (2009), the value premium can be interpreted via investment-to-capital in the denominator of the investment return, consistent with the evidence that value firms invest less than growth firms. In addition, our evidence shows that momentum can be interpreted via the expected investment-to-capital growth in the numerator of the investment return, consistent with the pattern that winners have higher expected growth rates than losers in the data.

Unfortunately, from Panels F and L in Fig. 4, the investment model fails to reproduce the momentum–value interaction. For price momentum, the winner-minus-loser alphas across the low, median, and high book-to-market terciles are 3.46%, −0.70%, and −6.80% per annum, respectively, which vary inversely with book-to-market in our model. Most seriously, the high-minus-low book-to-market alphas across the low, median, and high price momentum terciles are 11%, 10.07%, and 0.73%, respectively. For earnings momentum, the high-minus-low alphas across the low, median, and high earnings momentum terciles are 9.29%, 8.24%, and 5.41%, respectively. Another indication of this failure lies in the point estimates. While the $a$ and the $\kappa$ estimates from the investment model are generally small when fitting momentum portfolios only, Liu et al. (2009) report the $a$ estimate to be more than 20 and $\kappa$ about 0.5 when fitting the book-to-market deciles. Our evidence indicates that the investment model struggles to fit the momentum and book-to-market portfolios simultaneously with the same $a$ and $\kappa$ estimates.

### 4.4. *Risk analysis*

As noted, while connecting expected stock returns to firm characteristics, the investment model is silent about sources of risk. This subsection attempts to alleviate this weakness somewhat, with two sets of exploratory tests, long-run risks in investment returns and comovement among extreme momentum stocks.

#### 4.4.1. *Long-run risks in investment returns*

Bansal et al. (2005) show that aggregate consumption risks in cash flows help interpret the average return spread across the price momentum deciles. The following regression attempts to replicate their basic results in our sample:

$$g_{i,t} = \gamma_i \left( \frac{1}{K} \sum_{k=1}^{K} g_{c,t-k} \right) + u_{i,t}, \tag{5}$$

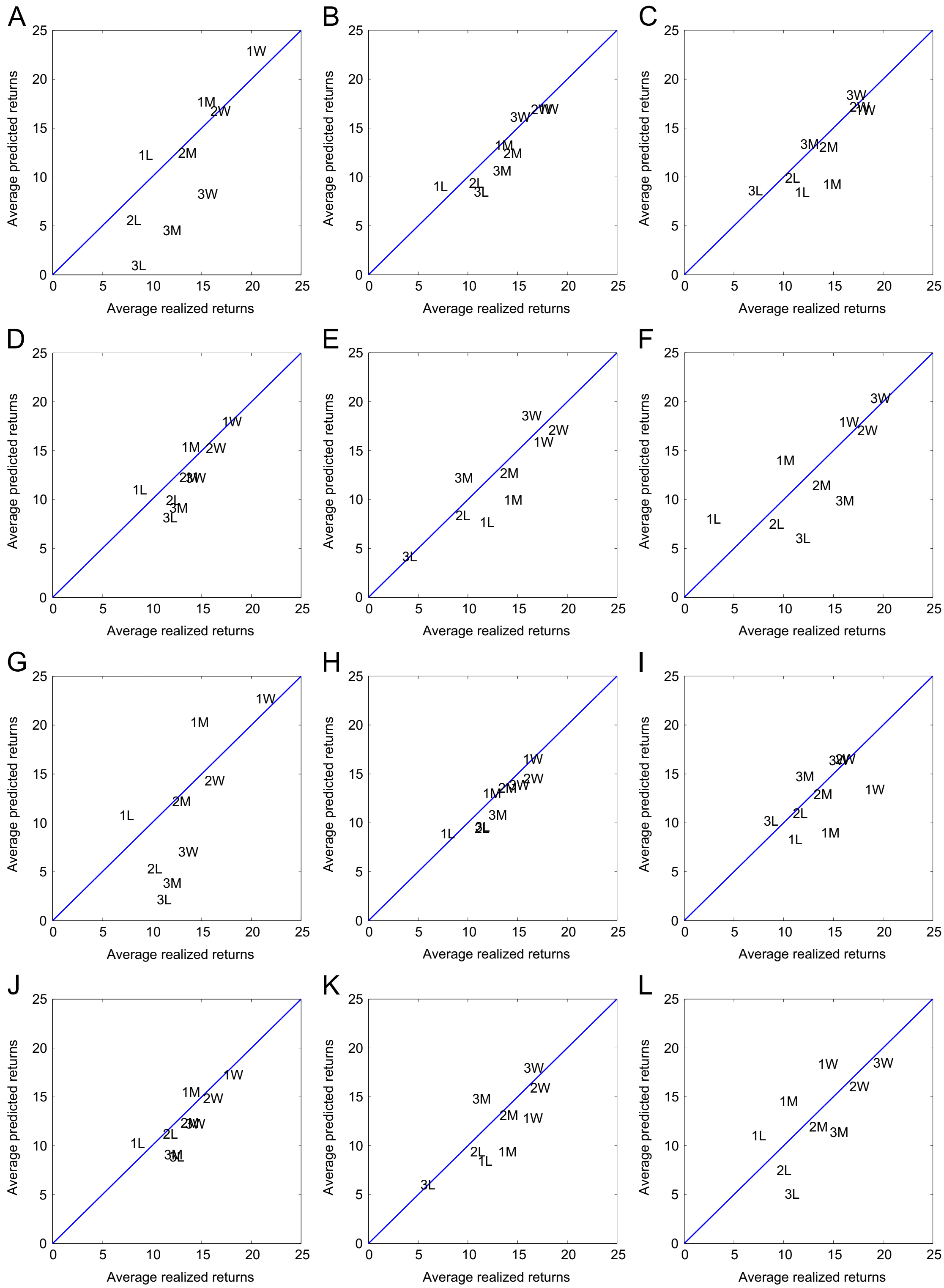


**Fig. 4.** Average predicted stock returns from the investment model versus average realized stock returns, two-way momentum portfolios. *Note*: The average predicted stock returns are given by $E_T[r^{Iw}_{it+1}]$, in which $E_T$ is the sample mean, and $r^{Iw}_{it+1}$ is levered investment returns. The estimates from one-stage GMM are used to construct levered investment returns. The average returns are in annual percent. In each panel, 1, 2, and 3 denote the terciles formed in the ascending order on the characteristic interacting with momentum, and $L, M,$ and $W$ denote the terciles in the ascending order on momentum. For instance, in Panel A, 1L is the portfolio as the interaction of the small tercile and the price momentum loser tercile. The other two-way portfolios are denoted analogously. Panel A: Size-$R^6$, Panel B: Age-$R^6$, Panel C: Trading volume-$R^6$, Panel D: Credit ratings-$R^6$, Panel E: Stock return volatility-$R^6$, Panel F: Book-to-market-$R^6$, Panel G: Size-SUE, Panel H: Age-SUE, Panel I: Trading volume-SUE, Panel J: Credit ratings-SUE, Panel K: Stock return volatility-SUE and Panel L: Book-to-market-SUE.

**Table 4**
Long-run risks in price and earnings momentum.

| | Stock returns | | | | Investment returns | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\gamma_i$ | se | $\overline{g}_i$ | se | $\gamma_i^\star$ | se | $\overline{g}_i^\star$ | se | $\gamma_{1i}^\star$ | se | $\gamma_{2i}^\star$ | se | $\gamma_{3i}^\star$ | se |
| Panel A: price momentum | | | | | | | | | | | | | | |
| *L* | −3.09 | 4.41 | −1.66 | 1.27 | 4.21 | 2.09 | −2.13 | 0.59 | 5.12 | 1.72 | 10.77 | 7.96 | 0.02 | 2.04 |
| 2 | −3.98 | 2.34 | −0.29 | 0.68 | 5.66 | 1.47 | 1.50 | 0.42 | 5.11 | 1.34 | 18.27 | 6.44 | 0.83 | 1.54 |
| 3 | −2.87 | 1.66 | −0.17 | 0.48 | 5.51 | 1.39 | 2.54 | 0.40 | 4.84 | 1.28 | 20.18 | 6.01 | 0.29 | 1.46 |
| 4 | −1.24 | 1.74 | 0.02 | 0.50 | 5.95 | 1.22 | 3.46 | 0.36 | 5.59 | 1.23 | 16.82 | 5.20 | 0.93 | 1.36 |
| 5 | 0.18 | 1.27 | 0.00 | 0.37 | 5.52 | 1.20 | 4.25 | 0.35 | 4.88 | 1.21 | 17.13 | 5.38 | 2.00 | 1.42 |
| 6 | 2.19 | 1.63 | 0.16 | 0.47 | 6.03 | 1.23 | 5.27 | 0.37 | 5.89 | 1.25 | 13.14 | 5.22 | 1.95 | 1.41 |
| 7 | 3.80 | 2.50 | 0.25 | 0.73 | 6.22 | 1.23 | 6.27 | 0.37 | 5.60 | 1.17 | 16.09 | 5.39 | 3.51 | 1.53 |
| 8 | 4.12 | 3.42 | 0.51 | 0.99 | 6.13 | 1.39 | 8.17 | 0.40 | 6.05 | 1.29 | 11.24 | 5.50 | 3.63 | 1.68 |
| 9 | 4.35 | 4.72 | 0.85 | 1.36 | 8.64 | 1.78 | 10.92 | 0.52 | 7.65 | 1.44 | 12.91 | 6.43 | 6.97 | 2.22 |
| *W* | 14.94 | 9.04 | 2.35 | 2.62 | 15.95 | 2.87 | 15.97 | 0.85 | 11.80 | 1.95 | 15.84 | 8.35 | 14.09 | 3.67 |
| *W*−*L* | 19.28 | 11.66 | 3.64 | 3.37 | 11.74 | 2.78 | 18.10 | 0.80 | 6.68 | 1.77 | 5.07 | 9.18 | 14.07 | 3.20 |
| Panel B: earnings momentum | | | | | | | | | | | | | | |
| *L* | −1.27 | 2.51 | 0.10 | 0.70 | 6.77 | 2.06 | 1.31 | 0.57 | 6.07 | 1.90 | 30.62 | 8.85 | 0.67 | 2.36 |
| 2 | −5.13 | 3.62 | −0.07 | 1.02 | 6.30 | 1.89 | 2.74 | 0.52 | 6.25 | 1.85 | 18.01 | 7.06 | 1.13 | 2.16 |
| 3 | −3.13 | 2.92 | −0.38 | 0.82 | 6.66 | 1.71 | 3.39 | 0.49 | 6.54 | 1.67 | 22.05 | 7.40 | 0.94 | 1.82 |
| 4 | −3.63 | 2.73 | −0.28 | 0.76 | 4.86 | 1.75 | 2.48 | 0.48 | 5.05 | 1.68 | 14.01 | 8.80 | −0.40 | 1.94 |
| 5 | 1.21 | 2.20 | 0.16 | 0.62 | 5.82 | 1.49 | 3.12 | 0.42 | 4.81 | 1.46 | 21.78 | 6.86 | 1.43 | 2.05 |
| 6 | −0.13 | 1.75 | 0.26 | 0.49 | 7.50 | 1.74 | 4.63 | 0.49 | 5.86 | 1.51 | 29.99 | 6.57 | 2.79 | 1.77 |
| 7 | 0.29 | 1.72 | 0.87 | 0.48 | 6.41 | 1.63 | 5.03 | 0.45 | 6.91 | 1.38 | 16.89 | 5.98 | −0.27 | 1.73 |
| 8 | 5.32 | 3.33 | 0.67 | 0.94 | 8.30 | 1.51 | 6.07 | 0.44 | 8.35 | 1.54 | 18.09 | 5.78 | 2.83 | 1.89 |
| 9 | 6.97 | 1.95 | 0.93 | 0.57 | 9.03 | 1.52 | 6.41 | 0.45 | 9.10 | 1.63 | 22.34 | 5.39 | 1.88 | 1.86 |
| *W* | 3.70 | 1.94 | 0.81 | 0.55 | 9.02 | 1.64 | 7.33 | 0.47 | 8.85 | 1.47 | 19.60 | 6.97 | 2.90 | 1.82 |
| *W*−*L* | 4.97 | 3.43 | 0.71 | 0.96 | 2.26 | 1.67 | 6.02 | 0.45 | 2.79 | 1.29 | −11.02 | 8.01 | 2.22 | 1.89 |

*Note*: $\gamma_i$ is the projection coefficient from the regression: $g_{i,t}=\gamma_i(\sum_{k=1}^{8}g_{c,t-k}/8)+u_{i,t}$, in which $g_{i,t}$ is demeaned log real cash flow growth rates on portfolio *i*, and $g_{c,t}$ is demeaned log real growth rates in aggregate consumption. Negative cash flow observations are treated as missing. $\overline{g}_i$ is the sample average log real dividend growth rate. Standard errors are reported in the columns denoted "se." $\gamma_i^\star$ is the projection coefficient from the regression: $g_{i,t}^\star=\gamma_i^\star(\sum_{k=1}^{8}g_{c,t-k}/8)+u_{i,t}$, in which $g_{i,t}^\star$ is demeaned log real fundamental cash flow growth rates on decile *i*. This cash flow is defined in Eq. (6). $\overline{g}_i^\star$ is the sample average of log real fundamental cash flow growth rates. $\gamma_{1i}^\star$ is the slope from regressing $g_{1i,t}^\star$, demeaned log real growth rates of $(1-\tau_{t+1})\kappa(Y_{it+1}/K_{it+1})$, $\gamma_{2i}^\star$ is the slope from regressing $g_{2i,t}^\star$, demeaned log real growth rates of $(1-\tau_{t+1})(a/2)(I_{it+1}/K_{it+1})^2$, and $\gamma_{3i}^\star$ is the slope from regressing $g_{3i,t}^\star$, demeaned log real growth rates of $\tau_{t+1}\delta_{it+1}$ on $\sum_{k=1}^{8}g_{c,t-k}/8$. Nominal variables are converted to real variables with the personal consumption expenditures deflator. The growth rates are in annual percent. *L* is the loser decile, *W* the winner decile, and *W*−*L* is the winner-minus-loser decile.

in which $K=8$, $g_{i,t}$ is demeaned log real dividend growth rates on momentum decile *i*, and $g_{c,t}$ is demeaned log real growth rates of aggregate consumption. The slope, $\gamma_i$, measures the cash flow's exposure to the long-term aggregate consumption growth (long-run risks).[15]

Consistent with Bansal et al. (2005), Panel A of Table 4 shows that price momentum winners have a higher slope than price momentum losers: 14.94 versus −3.09. The risk spread between the two extreme deciles is 19.28, albeit with a large standard error of 11.66. Winners also have a higher cash flow growth rate than losers: 2.35% versus −1.66% per annum, but the spread again has a large standard error.[16] For earnings momentum, Panel B shows that the evidence of long-run risks is substantially weaker. The risk spread between winners and losers is only 4.97, which has a large standard error of 3.43. The cash flow growth spread of 0.71% again has a large standard error, 0.96.

To examine long-run risks in investment returns, a new cash flow measure is defined as

$$D_{it+1}^\star \equiv (1-\tau_{t+1})\left[\kappa\frac{Y_{it+1}}{K_{it+1}}+\frac{a}{2}\left(\frac{I_{it+1}}{K_{it+1}}\right)^2\right]+\tau_{t+1}\delta_{it+1}, \tag{6}$$

based on the investment return equation (1). Because the denominator of the investment return equals marginal *q*, Eq. (1) implies that $D_{it+1}^\star/[1+(1-\tau_t)a(I_{it}/K_{it})]$ is analogous to the dividend yield, and the remaining piece of the investment return, $(1-\delta_{it+1})[1+(1-\tau_{t+1})a(I_{it+1}/K_{it+1})]/[1+(1-\tau_t)a(I_{it}/K_{it})]$, is analogous to the rate of capital gain. As such, $D_{it+1}^\star$ is analogous to dividends in the stock return.

[15] The quarterly data for seasonally adjusted real per capita consumption of nondurables and services are from Bureau of Economic Analysis. Personal consumption expenditures deflator is used to convert nominal variables to real variables. As in Bansal et al. (2005), stock repurchases are included when calculating dividends, and a trailing four-quarter average of quarterly cash flows is used to adjust for seasonality in quarterly dividends.

[16] Because of a few negative cash flows (dividends plus net repurchases), which are treated as missing, the slope, $\gamma_i$, for the winner-minus-loser decile is not identical to the spread in $\gamma_i$ between winners and losers. Similarly, the cash flow growth rate of the winner-minus-loser decile is not identical to the growth rate spread.

**Table 5**
Comovement among extreme momentum stocks.

| | | Panel A: stock returns | | | | | Panel B: levered investment returns | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cnsmr | Manuf | HiTec | Hlth | Other | Cnsmr | Manuf | HiTec | Hlth | Other |
| | | Mean in the upper triangular = 0.86 | | | | | Mean in the upper triangular = 0.52 | | | | |
| L | Cnsmr | 1 | 0.88 | 0.87 | 0.83 | 0.92 | 1 | 0.69 | 0.57 | 0.41 | 0.57 |
| L | Manuf | 0.88 | 1 | 0.83 | 0.80 | 0.89 | 0.56 | 1 | 0.59 | 0.44 | 0.63 |
| L | HiTec | 0.81 | 0.82 | 1 | 0.86 | 0.88 | 0.35 | 0.34 | 1 | 0.25 | 0.66 |
| L | Hlth | 0.74 | 0.74 | 0.82 | 1 | 0.84 | 0.32 | 0.34 | 0.18 | 1 | 0.35 |
| L | Other | 0.91 | 0.89 | 0.83 | 0.78 | 1 | 0.49 | 0.59 | 0.35 | 0.22 | 1 |
| | | Mean in the lower triangular = 0.82 | | | | | Mean in the lower triangular = 0.37 | | | | |
| | | Mean in the upper triangular = 0.83 | | | | | Mean in the upper triangular = 0.30 | | | | |
| W | Cnsmr | 1 | 0.83 | 0.85 | 0.75 | 0.90 | 1 | 0.35 | 0.12 | 0.21 | 0.26 |
| W | Manuf | 0.88 | 1 | 0.82 | 0.74 | 0.86 | 0.33 | 1 | 0.27 | 0.26 | 0.24 |
| W | HiTec | 0.82 | 0.81 | 1 | 0.85 | 0.86 | 0.33 | 0.51 | 1 | 0.05 | 0.56 |
| W | Hlth | 0.75 | 0.71 | 0.80 | 1 | 0.79 | 0.22 | 0.39 | 0.25 | 1 | 0.09 |
| W | Other | 0.91 | 0.91 | 0.84 | 0.75 | 1 | 0.14 | 0.24 | 0.16 | 0.20 | 1 |
| | | Mean in the lower triangular = 0.82 | | | | | Mean in the lower triangular = 0.28 | | | | |

*Note*: Each extreme momentum decile is split into five sub-deciles based on a stock's five-industry classification. The table reports pairwise correlations and their average among the five sub-deciles within a given decile. The pairwise correlations are calculated for both stock returns and levered investment returns constructed with the parameter estimates from one-stage GMM. For each matrix of pairwise correlations, the upper triangular is for price momentum, and the lower triangular for earnings momentum. *L* is the loser decile, and *W* the winner decile. Within the five-industry classification, Cnsmr is consumer durables, nondurables, wholesale, retail, and some services (laundries, repair shops); Manuf is manufacturing and energy; HiTec is business equipment, telephone and television transmission; Hlth is healthcare, medical equipment, and drugs; and Other is all the other industries including mines, construction, construction materials, transportation, hotels, business services, and entertainment. The sample is from July 1972 to December 2012.

For price momentum, Panel A of Table 4 shows that the fundamental cash flow growth has higher long-run risks in winners than in losers: 15.95 versus 4.21. The spread of 11.74 is significant with a small standard error of 2.78. The cash flow growth is also higher in winners than in losers: 15.97% versus −2.13%, and the spread of 18.10% is highly significant. The remainder of Panel A shows that winners have significantly higher cash flow risks than losers in the sales-to-capital growth and in the growth of depreciation rate, but not in the growth rate of squared investment-to-capital. For earnings momentum, Panel B shows higher long-run risks in the fundamental cash flow growth in winners than in losers. However, the spread of 2.26 has a large standard error of 1.67. The cash flow growth is again higher on average in winners than in losers: 7.33% versus 1.31%, and the spread is significant. Overall, our evidence connects long-run risks in stock returns in Bansal et al. (2005) to similar long-run risks in economic fundamentals. As such, the evidence helps interpret why winners have higher long-run risks than losers, especially for price momentum.

### 4.4.2. *Comovement among extreme momentum stocks*

Another measure of risk is comovement among extreme momentum stocks. Winners tend to comove with other winners, and losers tend to comove with other losers. This comovement gives rise to the power of the momentum factor in accounting for the cross-sectional variation of stock returns (e.g., Carhart, 1997). To measure the comovement, a given extreme momentum decile is split into five sub-deciles based on a stock's five-industry classification. Pairwise correlations among the five sub-deciles for a given decile are calculated for both stock returns and levered investment returns. Only five industries are used, and the sample starts only in July 1972 because some industries have fewer than ten firms in early years.

For stocks returns, Table 5 shows that the average pairwise correlation ranges from 0.82 for both extreme deciles on earnings momentum to 0.86 for the loser decile on price momentum. The investment model reproduces positive comovement among extreme deciles but the correlations are lower in magnitude. The average correlation ranges from 0.28 for the winner decile on earnings momentum to 0.52 for the loser decile on price momentum. Untabulated results also show that leverage and corporate bond returns are quantitatively important for the comovement. For instance, setting leverage to the time series mean for each sub-decile reduces the average pairwise correlation to 0.22 for the loser decile on price momentum, and setting corporate bond returns to their time series mean reduces the average correlation to 0.19 for the same decile. As such, the evidence indicates the existence of the comovement among stock returns in excess of what can be accounted for by economic fundamentals.

## 5. Conclusion

The first principles of investment imply that expected stock returns are tied with the expected marginal benefit of investment divided by the marginal cost of investment. Winners have higher expected investment-to-capital growth and expected sales-to-capital, which are two major components of the expected marginal benefit of investment. As such, winners earn higher expected stock returns than losers. The investment model also captures the reversal of momentum in long horizons, long-run risks in momentum, as well as the interaction of momentum with several firm characteristics.

However, the model fails to reproduce the procyclicality of momentum as well as its negative interaction with book-to-market.

Momentum is often interpreted as a sign of investor irrationality. Our evidence indicates that managers align investment policies properly with the costs of capital, and that momentum seems consistent with this alignment. Our evidence does not prove rationality. A low cost of capital could reflect rationally low market prices of risk demanded by investors or sentiment of investors who are irrationally optimistic. However, momentum does not prove irrationality either. If resulting from the optimal investment behavior of managers, momentum does not have direct implications about the behavior of investors.

Two directions are possible for future research. First, the failure of the model in fitting the momentum and book-to-market portfolios jointly indicates that the baseline model with only two parameters is too parsimonious. One can introduce industry-specific parameters to enrich the model and to improve its performance. Second, Asness et al. (2013) document consistent value and momentum across diverse markets and asset classes such as currencies. One can extend the investment model to international settings and estimate the richer model on global and currencies data.

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