

Anomalies

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Abstract

I develop a theory of asset pricing anomalies based on the value maximization of firms. Under certain conditions, stock return equals investment return, which is directly tied with firm characteristics. This equation can potentially generate many anomalies such as the relations of future stock returns with market-to-book, investment and disinvestment, seasoned equity offerings, tender offers and stock repurchases, dividend omissions and initiations, expected profitability, profitability, and more important, earnings announcement. The theory also implies a new asset pricing test.

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1 Introduction

A large body of empirical literature in financial economics has documented relations of future stock returns with characteristics and corporate events, relations that are called anomalies because they are hard to explain using current asset pricing models (e.g., Fama (1998) and Schwert (2003)). Many believe that these anomalies are strong evidence against efficient markets and rational expectations (e.g., Shleifer (2000) and Barberis and Thaler (2003)).

I construct a neoclassical, Q -theoretical foundation for time-varying expected returns in connection with corporate policies. If the operating-profit and the adjustment-cost functions have the same degree of homogeneity, stock return equals investment return, which is directly tied with characteristics and corporate policies via the first principles of optimal investment.

By signing the partial derivatives of investment returns, I demonstrate analytically that the Q -theory is potentially consistent with many anomalies often interpreted as over- and underreaction in inefficient markets (e.g., Barberis, Shleifer, and Vishny (1998), Daniel, Hirshleifer, and Subrahmanyam (1998), and Hong and Stein (1999)). These anomalies include:

- The investment-disinvestment anomaly: The investment-to-asset ratio is negatively correlated, but the disinvestment-to-asset ratio is positively correlated with future returns. This anomaly is stronger in firms with high operating income-to-capital.
- The value anomaly: Average returns correlate negatively with market-to-book, and the magnitude of this correlation decreases with the market value.
- The payout anomaly: When firms tender their stocks or announce share repurchases or dividend initiations, they earn positive long-term abnormal returns, and the magnitude of the abnormal returns is stronger in value firms than in growth firms.

- The seasoned-equity-offering (SEO) anomaly: Firms conducting SEOs earn lower average returns in the next three to five years than nonissuing firms, and the magnitude of this underperformance is stronger in small firms than in big firms.
- The expected-profitability anomaly: Expected profitability correlates positively with expected returns, and this correlation decreases with the market value.
- The profitability anomaly: Given market-to-cash flows or market-to-book, more profitable firms earn higher average returns. This relation is stronger in small firms.
- The post-earnings-announcement drift (earnings momentum): Firms with high earnings surprise earn higher average returns than firms with low earnings surprise, and this anomaly is stronger in small firms.

In a nutshell, I demonstrate that, much like aggregate expected returns that vary over business cycles (e.g., Campbell and Cochrane (1999)), expected returns in the cross section vary with firm characteristics, corporate policies, and events.

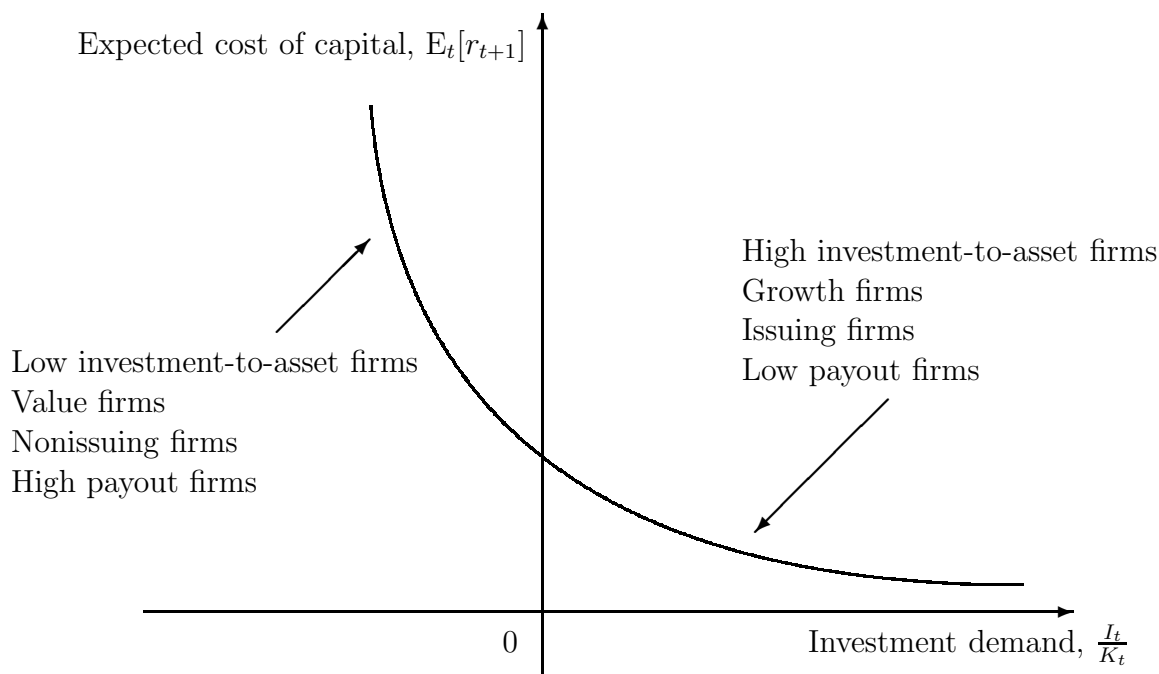
Intuitively, investment return from time t to $t+1$ equals the ratio of the marginal profit of investment at $t+1$ divided by the marginal cost of investment at t . This equation suggests two economic mechanisms that are potential driving forces of these anomalies.

The first four anomalies can be explained by optimal investment. The Q -theory is a theory of investment demand — the downward-sloping investment-demand function derived from the first principles of optimal investment implies a negative relation between cost of capital (i.e., expected return) and investment demand. Basically, investment-to-asset increases with net present value of capital (e.g., Brealey and Myers (2003, Chapter 2)), and the net present value decreases with cost of capital. Controlling for expected future cash flows, high cost of

capital implies low net present value, which in turn implies low investment demand. Low cost of capital implies high net present value, which in turn implies high investment demand.

Figure 1 plots the downward-sloping investment-demand function. The negative slope of this function suggests that expected return decreases with positive investment but increases with the magnitude of disinvestment, i.e., the investment-disinvestment anomaly. The figure also shows the distribution of firms with related characteristics other than investment-to-asset, $\frac{I_t}{K_t}$, across the investment-demand curve. Similar to high investment-to-asset firms, growth firms, issuing firms, and low payout firms are distributed on the right end of the curve associated with low expected returns, whereas similar to low investment-to-asset firms, value firms, nonissuing firms, and high payout firms are distributed on the left end of the curve associated with high expected returns.

Figure 1. The Downward-Sloping Investment-Demand Function



Intuitively, investment rate is an increasing function of marginal q , i.e., the present value of future marginal profits of capital, which is in turn proportional to market-to-book. The negative slope of the investment-demand function then implies a negative relation between expected return and market-to-book. The payout anomaly follows because firms' cash-flow constraint (that equates the sources with the uses of funds) implies a negative relation between the payout and investment rates. And the SEO anomaly follows because the cash-flow constraint implies a positive relation between the equity-financing and investment rates.

With decreasing returns to scale or strictly convex adjustment costs, the relation between expected return and market-to-book is convex — in the example of quadratic adjustment costs, the investment-demand function is also convex. This convexity manifests itself, by the chain rule of partial derivatives, as the stronger value anomaly in small firms, the stronger SEO anomaly in small firms, and the stronger payout anomaly in value firms.

In contrast, the three earnings-related anomalies can be explained by the marginal product of capital (MPK) at time $t+1$ in the numerator of investment return through the MPK-mechanism. Specifically, MPK is proportional to profitability, a property that implies a positive relation between expected profitability and expected return. This positive relation in turn explains the profitability anomaly because profitability is a strong, positive predictor of future profitability. And because earnings surprise and profitability are both scaled earnings, they should contain similar information on future profitability. If so, earnings surprise should correlate positively with expected returns, as in the post-earnings-announcement drift.

Intriguingly, the Q -explanation of anomalies does not involve risk, at least directly, even though the model is entirely rational. The reason is that I derive expected returns from firms' optimality conditions, instead of consumers'. As a result, the stochastic discount fac-

tor (SDF) and its covariances with returns do not directly enter the expected-return determination. Characteristics are sufficient statistics for expected returns! Therefore, the debate on covariances versus characteristics in efficient markets in empirical finance (e.g., Daniel and Titman (1997) and Davis, Fama, and French (2000)) is not a well-defined question.

I also propose the Q -representation of expected returns as a new empirical asset pricing model. Although internally consistent with the beta- and the SDF-framework in theory, the Q -representation is likely to have practical advantages over these two standard models. The reason is that estimated costs of equity from beta-pricing models are extremely imprecise even at the industry level (e.g., Fama and French (1997)). But the Q -representation avoids the difficult tasks of estimating covariances and of identifying the right form of the SDF.

The insight that stock and investment returns are equal first appears in Cochrane (1991). Cochrane (1991, 1996) is also among the first to study asset prices from firms' perspective. Restoy and Rockinger (1994) formally establish this equivalence under linear homogeneity. An early version of Gomes, Yaron, and Zhang (2004) extends the result under debt financing. I extend the result under homogeneity of the same degree for the operating-profit and adjustment-cost functions. I differ further from these papers that focus on aggregate investment returns, because I aim to understand anomalies in the cross section.

The Q -theory is originated by Brainard and Tobin (1968) and Tobin (1969). Hayashi (1982) establishes the equivalence between marginal q and average Q under linear homogeneity. Abel and Eberly (1994) extend this result into a stochastic setting with partial irreversibility and fixed costs proportional to capital. They also show that marginal q is proportional to average Q when the operating-profits and the adjustment-cost functions are homogeneous of the same degree, a result I use extensively. The Q -theory has been used

mostly to explain the behavior of investment. But I offer the prospects of its large-scale applications to the cross section of returns.

My work shares its long-term goal with the growing literature, pioneered by Berk, Green, and Naik (1999), the literature that aims to understand the real determinants of the cross section of returns.¹ I contribute by expanding the scope of explained anomalies and by unifying many anomalies under a single, analytical framework. I also propose a new empirical asset pricing model with which many ideas of this highly theoretical literature can be tested. Comparisons with specific papers are presented throughout Section 3.

The rest of the paper is organized as follows. Section 2 sets up the model and establishes the equivalence between stock and investment returns. Section 3 uses this equivalence to explain anomalies, Section 4 discusses empirical implications of my theoretical results, and Section 5 concludes. Appendix A briefly reviews the anomalous evidence that motivates this paper, and Appendix B contains all the proofs not in the main text.

2 The Model of the Firm

This section presents the basic elements of the Q -theory. My exposition is heavily influenced by Abel and Eberly (1994) and an early version of Gomes, Yaron, and Zhang (2004). Section 2.1 describes the basic environment. Section 2.2 characterizes the behavior of firm value-maximization, and establishes the equivalence between stock and investment returns.

¹Other important examples include Berk (1995), Johnson (2002), Berk, Green, and Naik (2004), Carlson, Fisher, and Giammarino (2004a, 2004b), Chen (2004), Cooper (2004), Gomes, Kogan, and Zhang (2003), Gomes, Yaron, and Zhang (2004), Gourio (2004), Kogan (2004), Menzly, Santos, and Veronesi (2004), Pastor and Veronesi (2004), Whited and Wu (2004), and Zhang (2005).

2.1 The Environment

Consider a firm that uses capital and a vector of costlessly adjustable inputs, such as labor, to produce a perishable output. The firm chooses the levels of these inputs each period to maximize its operating profit, defined as its revenue minus the expenditures on these inputs. Taking the operating profit as given, the firm then chooses optimal investment to maximize its market value. Capital investment involves costs of adjustment.

2.1.1 The Operating-Profit Function

Let $\Pi_t = \Pi(K_t, X_t)$ denote the maximized operating profit at time t , where K_t is the capital stock at time t and X_t is a vector of random variables representing exogenous shocks to the operating profit, such as aggregate and firm-specific shocks to production technology, shocks to the prices of costlessly adjusted inputs, or industry- and firm-specific shocks to the demand of the output produced by the firm.

Assumption 1 *The operating profit function is homogeneous of degree α with $\alpha \leq 1$:*

$$\Pi(K_t, X_t) = \Lambda(X_t)K_t^\alpha \quad \text{where} \quad \Lambda(X_t) > 0 \quad (1)$$

If $\alpha = 1$, the operating-profit function displays linear homogeneity in K_t . This applies to a competitive firm that is a price-taker in output and factor markets.² When $\alpha < 1$, the firm

²This can be seen from the static maximization problem of the firm that chooses the vector of costlessly adjustable inputs. Let \mathbf{L}_t denote this vector and $F(K_t, \mathbf{L}_t, X_t)$ denote the revenue function that is linearly homogenous in K_t and \mathbf{L}_t . If the firm is a price-taker, its operating profit can be written as:

$$\Pi(K_t, X_t) = \max_{\mathbf{L}_t} \{F(K_t, \mathbf{L}_t, X_t) - \mathbf{W}'_t \mathbf{L}_t\} = \max_{\mathbf{L}_t/K_t} \{[F(1, \mathbf{L}_t/K_t, X_t) - \mathbf{W}'_t(\mathbf{L}_t/K_t)] K_t\} = \Lambda(X_t)K_t$$

where \mathbf{W}_t is the vector of market prices of the costlessly adjustable inputs, the second equality follows from the linear homogeneity of $F(K, \mathbf{L}, X)$ in K and \mathbf{L} , and the third equality follows by defining $\Lambda(X_t) \equiv \max_{\mathbf{L}_t/K_t} \{[F(1, \mathbf{L}_t/K_t, X_t) - \mathbf{W}'_t(\mathbf{L}_t/K_t)]\}$. The first-order condition with respect to \mathbf{L}_t says that $F_2(K_t, \mathbf{L}_t, X_t) = \mathbf{W}_t$. The linear homogeneity of $F(K_t, \mathbf{L}_t, X_t)$ in K_t and \mathbf{L}_t then implies that $F(1, \mathbf{L}_t/K_t, X_t) - \mathbf{W}'_t(\mathbf{L}_t/K_t) = F_1(1, \mathbf{L}_t/K_t, X_t)$ which is clearly positive. Therefore, $\Pi_1(K_t, X_t) = \Lambda(X_t) > 0$. If $F_3(K_t, \mathbf{L}_t, X_t)$ is positive, then $\Lambda'(X_t) > 0$.

has market power (e.g., Cooper and Ejarque (2001)).

From Assumption 1,

$$\alpha\Pi(K_t, X_t) = \Pi_1(K_t, X_t)K_t \quad (2)$$

Marginal product of capital is strictly positive, $\Pi_1(K_t, X_t) > 0$, where subscript i denotes the first-order partial derivative with respect to the i^{th} argument. Multiple subscripts denote high-order partial derivatives. $\Pi_1(K_t, X_t)$ decreases with capital, reflecting decreasing return to scale, $\Pi_{11}(K_t, X_t) \leq 0$, where the inequality is strict when $\alpha < 1$. Finally, $\Pi_{111}(K_t, X_t) \geq 0$.

More important, equation (2) implies that marginal product of capital, Π_1 , is also proportional to the average product of capital, $\frac{\Pi(K_t, X_t)}{K_t}$. This ratio corresponds roughly to accounting profitability (earnings-to-book) plus depreciation rate. The operating profit in the model corresponds approximately to earnings plus capital depreciation in the data. This assumes that accruals are only used to mitigate the accounting timing and matching problems that deviate operating cash flow from earnings in practice (e.g., Dechow (1994)). These accounting problems are abstracted from the model.

2.1.2 The Augmented Adjustment-Cost Function

Capital accumulates according to:

$$K_{t+1} = I_t + (1 - \delta)K_t \quad (3)$$

Thus end-of-period capital equals real investment plus beginning-of-period capital net of depreciation. Capital depreciates at a fixed proportional rate of δ .

When the firm invests, it incurs costs because of: (i) purchase/sale costs, (ii) convex costs of physical adjustment, and (iii) weakly convex costs of raising capital when the sum of the

purchase/sale and physical adjustment costs is higher than the operating profit.

(i) Purchase/sales costs are incurred when the firm buys or sells uninstalled capital. When the firm disinvests, this cost is negative. For analytical convenience, I assume that the relative purchase price and relative sale price of capital are both equal to unity. This differs from Abel and Eberly (1994), who assume that purchase price is higher than sale price to capture costly reversibility because of, for example, firm-specificity of capital and adverse selection in the market for used capital. In this case, the purchase/sale cost function is not differentiable at $I_t=0$. My assumption retains this differentiability. Costly reversibility can still be captured by letting the convex costs of disinvestment be uniformly higher than those of investment with equal magnitudes (e.g., Hall (2001) and Zhang (2004)).

(ii) Convex costs of physical adjustment are nonnegative costs that are zero when $I_t=0$. These costs are continuous, strictly convex in I_t , non-increasing in capital K_t , and differentiable with respect to I_t and K_t everywhere. The second-order partial derivative of the convex-cost function with respect to K_t is nonnegative. It is straightforward to verify that the standard quadratic, convex adjustment-cost function satisfies all these assumptions.

(iii) Costs of raising capital are incurred when the financial deficit, denoted O_t , is strictly positive. I define O_t as the higher value between zero and the sum of the purchase/sale costs and convex costs of adjustment minus the operating profit. I assume that the financing-cost function is continuous, weakly convex in O_t (and hence in I_t) and decreasing in K_t . Its first-order partial derivative with respect to O_t (and hence with respect to I_t) is zero when $O_t=0$. The financing-cost function is differentiable with respect to O_t (and hence with respect to I_t) and K_t everywhere. And the second-order partial derivative of the function with respect to K_t is nonnegative. Previous studies of financing costs (e.g., Gomes (2001) and Hennessy

and Whited (2004)) assume that the costs are proportional to the amount of funds raised. And quadratic costs can be defined as $\frac{b}{2} \left(\frac{O_t}{K_t}\right)^2 K_t$ with $b > 0$. Both the proportional and the quadratic financing-cost functions satisfy the aforementioned assumptions.

The flip side of financial deficit is free cash flow, denoted C_t . I define C_t as the higher value between zero and the operating profit minus the sum of the purchase/sale costs and the convex costs of adjustment. I assume that whenever C_t is strictly positive, the firm pays it back to its shareholders either in the form of dividends or stock repurchases. The model is silent on the behavior of cash hoarding or on the form of payout. Further, I assume that the firm does not pay any extra costs when paying cash out of the firm. Therefore, the firm either raises capital or distributes payout, but never at the same time.

The total cost of investment represents the sum of purchase/sale costs, convex costs of physical adjustment, and costs of raising capital. I denote the total cost as $\Phi(I_t, K_t)$, and refer to it as the augmented adjustment-cost function. To summarize,

Assumption 2 *The augmented adjustment-cost function $\Phi(I_t, K_t)$ satisfies:*

$$\Phi_2(I_t, K_t) \leq 0; \quad \Phi_{22}(I_t, K_t) \geq 0; \quad \text{and} \quad \Phi_{11}(I_t, K_t) > 0;$$

The most important technical assumption is stated explicitly below:

Assumption 3 *The augmented adjustment-cost function is homogeneous of the same degree, α , in I_t and K_t , as the operating-profit function is in K_t . In other words,*

$$\Phi(I_t, K_t) = G \left(\frac{I_t}{K_t} \right) K_t^\alpha \tag{4}$$

Coupled with Assumption 2, Assumption 3 implies that $G''(\cdot) > 0$ and that

$$\alpha\Phi(I_t, K_t) = \Phi_1(I_t, K_t)I_t + \Phi_2(I_t, K_t)K_t \quad (5)$$

Assumption 3 is necessary in establishing the equivalence between stock and investment returns (see the proof of Proposition 2 in Appendix B). But how restrictive is Assumption 3? Abel and Eberly (1994) discuss its content for the case of linear homogeneity. I follow their exposition except for the financing-cost function. The linear homogeneity of $\Phi(I_t, K_t)$ means that each of its three components is linearly homogenous. (i) A doubling of I_t doubles the purchase/sale costs that are linear in I_t , and are independent of K_t . (ii) The investment literature typically assumes that physical adjustment costs are linearly homogenous (e.g., Hayashi (1982), Abel and Blanchard (1983), and Abel and Eberly (1994)). And (iii) the proportional and quadratic financing-cost functions are linearly homogeneous in I_t and K_t .

Relative to the specification in Abel and Eberly (1994), my augmented adjustment-cost function adds the convex costs of financing, but ignores the wedge between purchase and sale prices of capital and fixed costs of adjustment. The fixed costs of raising capital are not included either. Incorporating these features will compromise the differentiability of $\Phi(I_t, K_t)$ with respect to I_t at the two points where $I_t=0$ and $O_t=0$. The theory below works almost everywhere but at these two points where investment return is ill-defined because Φ_1 does not exist (see equation (15) below). Although not implemented here, it is possible to define two different investment returns at these two points using the left- and the right-side partial derivatives of Φ with respect to I_t .

More important, including the wedge between the purchase and sale prices of capital and fixed costs of investment and raising capital leaves the crucial Assumption 3 unaltered. As

argued in Abel and Eberly (1994), the purchase/sale costs are proportional to I_t . And the fixed costs are linearly homogenous in K_t , if they reflect the costs of interrupting production, and are therefore proportional to the operating profit and to capital.

Finally, it is ultimately an empirical question how restrictive Assumption 3 is. But I note that the special case of $\alpha = 1$ is standard in the empirical investment literature (e.g., Hubbard (1998) and Erickson and Whited (2000)). Further, several numerically solved models such as Cooper (2005), Kogan (2004), and Zhang (2005) yield qualitatively similar results as my analytical results. In particular, Zhang's model structure is very similar to mine, and the only relevant difference is that in his model the operating-profit and the adjustment-cost functions have different degrees of homogeneity.

2.2 Dynamic Value Maximization

I now characterize firm's value-maximization behavior. The dynamic problem is:

$$V(K_t, X_t) = \max_{\{I_{t+j}, K_{t+1+j}\}_{j=0}^{\infty}} \mathbb{E}_t \left[\sum_{j=0}^{\infty} M_{t,t+j} (\Pi(K_{t+j}, X_{t+j}) - \Phi(I_{t+j}, K_{t+j})) \right] \quad (6)$$

where $V(K_t, X_t)$ is the cum-dividend market value — when $j = 0$, $\Pi(K_t, X_t) - \Phi(I_t, K_t)$ is included in $V(K_t, X_t)$. $M_{t,t+j} > 0$ is the stochastic discount factor from time t to $t+j$. $M_{t,t} = 1$ and $M_{t,t+i} M_{t+i+1,t+j} = M_{t,t+j}$ for some integer i between 0 and j . For notational simplicity, I use M_{t+j} to denote $M_{t,t+j}$ whenever the starting date is t .

2.2.1 Marginal q , Tobin's Average Q , and Market-to-Book

Lemma 1 *Under Assumptions 1 and 3, the value function is also homogenous of degree α :*

$$\alpha V(K_t, X_t) = V_1(K_t, X_t) K_t$$

Define Tobin's average Q as $\widehat{Q}_t \equiv \frac{V(K_t, X_t)}{K_t}$, then $V_1(K_t, X_t) = \alpha \widehat{Q}_t$.

Let q_t be the present-value multiplier associated with capital accumulation equation (3).

The Lagrange formulation of the firm value, $V(K_t, X_t)$, is then:

$$\max_{\{I_{t+j}, K_{t+1+j}\}_{j=0}^{\infty}} \mathbb{E}_t \left[\sum_{j=0}^{\infty} M_{t+j} (\Pi(K_{t+j}, X_{t+j}) - \Phi(I_{t+j}, K_{t+j}) - q_{t+j} [K_{t+j+1} - (1 - \delta)K_{t+j} - I_{t+j}]) \right] \quad (7)$$

The first-order conditions with respect to I_t and K_{t+1} are, respectively,

$$q_t = \Phi_1(I_t, K_t) \quad (8)$$

$$q_t = \mathbb{E}_t [M_{t+1} [\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}) + (1 - \delta)q_{t+1}]] \quad (9)$$

Solving equation (9) recursively yields an economic interpretation for marginal q :

Lemma 2 *Marginal q is the expected present value of marginal profits of capital:*

$$q_t = \mathbb{E}_t \left[\sum_{j=1}^{\infty} M_{t+j} (1 - \delta)^{j-1} (\Pi_1(K_{t+j}, X_{t+j}) - \Phi_2(I_{t+j}, K_{t+j})) \right] \quad (10)$$

Proposition 1 (The Link between Marginal q and Market-to-Book) *Define the ex-dividend firm value, P_t , as:*

$$P_t \equiv P(K_t, K_{t+1}, X_t) = V(K_t, X_t) - \Pi(K_t, X_t) + \Phi(I_t, K_t) \quad (11)$$

And define the market-to-book equity as $Q_t \equiv \frac{P_t}{K_{t+1}}$ then under Assumptions 1 and 3,

$$q_t = \alpha Q_t \quad (12)$$

In the continuous time formulation of the Q -theory (e.g., Hayashi (1982) and Abel and Eberly (1994)), marginal q_t is proportional to Tobin's average Q_t , i.e., $q_t = \alpha \widehat{Q}_t$. But in

discrete time, $V_1(K_t, X_t)$ is not exactly marginal q_t . The time-to-build convention reflected in the capital accumulation equation (3) implies that one unit of investment today only becomes effective next period. As a result, q_t and \widehat{Q}_t are linked through:

$$q_t = \alpha E_t[M_{t+1}\widehat{Q}_{t+1}] \quad (13)$$

To see this, note the derivative of equation (7) with respect to K_t is $V_1(K_t, X_t) = \Pi_1(K_t, X_t) - \Phi_2(I_t, K_t) + q_t(1 - \delta)$. Equation (13) then follows from Lemma 1 and equation (9).

Several useful properties of $\Phi(I_t, K_t)$ evaluated at the optimum can be established using equation (8) and the link between marginal q and average \widehat{Q}_t .

Lemma 3 *Under Assumptions 1 and 2, the augmented adjustment-cost function $\Phi(I_t, K_t)$, when evaluated at the optimum, satisfies:*

$$\Phi_1(I_t, K_t) > 0; \quad \Phi_{12}(I_t, K_t) \leq 0; \quad \text{and} \quad \Phi_{122}(I_t, K_t) \geq 0$$

Proof. See Appendix B for the proof of the last two inequalities. The first inequality can be shown as follows. From Assumptions 1 and 2, $\Pi_1 > 0$ and $\Phi_2 \leq 0$, equation (10) then implies that $q_t > 0$. But from equation (8), Φ_1 equals q_t at the optimum. Therefore, although Φ_1 in general can be positive, negative, or zero when $I_t \leq 0$, it is strictly positive at the optimum. Equivalently, $G'(\cdot)$ is strictly positive at the optimum. ■

2.2.2 Investment and Stock Returns

Combining the first-order conditions in equations (8) and (9) yields:

$$E_t[M_{t+1}r_{t+1}^I] = 1 \quad (14)$$

where r_{t+1}^I denotes the investment return:

$$r_{t+1}^I = \frac{\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}) + (1 - \delta)\Phi_1(I_{t+1}, K_{t+1})}{\Phi_1(I_t, K_t)} \quad (15)$$

The investment-return equation (15) is very intuitive — r_{t+1}^I can be interpreted as the ratio of the marginal benefit of investment at time $t+1$ divided by the marginal cost of investment at time t . The denominator, $\Phi_1(I_t, K_t)$, is the marginal cost of investment. By optimality, it equals the marginal q_t , the expected present value of marginal profits of investment. In the numerator of equation (15), $\Pi_1(K_{t+1}, X_{t+1})$ is the extra operating profit from the extra capital at $t+1$; $-\Phi_2(I_{t+1}, K_{t+1})$ captures the effect of extra capital on the augmented adjustment cost; and $(1 - \delta)\Phi_1(I_{t+1}, K_{t+1})$ is the expected present value of marginal profits evaluated at time $t+1$, net of depreciation.

Proposition 2 (*The Equivalence between Stock and Investment Returns*) Define stock return as:

$$r_{t+1}^S \equiv \frac{P_{t+1} + \Pi(K_{t+1}, X_{t+1}) - \Phi(I_{t+1}, K_{t+1})}{P_t} \quad (16)$$

Then $E_t[M_{t+1}r_{t+1}^S] = 1$. Under Assumptions 1 and 3, stock return equals investment return:

$$r_{t+1}^S = r_{t+1}^I \quad (17)$$

Given this equivalence, I will use the common notation r_{t+1} to denote both returns.

3 Understanding Anomalies

The equivalence between stock and investment returns is an extremely powerful result. It provides a theoretically motivated, analytical link between expected returns and firm characteristics, a link that can serve as an economic foundation for understanding anomalies.

Developing this foundation is the heart of this paper. I first discuss in Section 3.1 the methodology of the Q -determination of expected returns, and its relation to the standard risk-based determination. Section 3.2 fixes the basic intuition using two canonical examples. And Section 3.3 extends the intuition into the more general Q -theoretical framework.

3.1 Methodology

My analytical methods are very simple. They basically amount to taking and signing partial derivatives of the expected investment return in equation (15) with respect to various anomaly-related variables. Using partial derivatives is reasonable because to establish a new anomaly, empiricists often control for other known anomalies, a practice corresponding naturally to partial derivatives.³ Cochrane (1991, 1996) uses similar techniques to explain the return-investment relations. Similar methods are commonly used in the empirical literature to develop testable hypotheses from valuation models (e.g., Fama and French (2004)).

As a more fundamental departure from the traditional asset pricing approach, which derives expected returns from consumers' first-order conditions and determines expected returns through risk, I follow Cochrane (1991) and derive expected returns from firms' first-order conditions. As a result, expected returns are directly tied with firm characteristics.⁴ Intriguingly, the stochastic discount factor, M_{t+1} , and its covariances with returns (i.e., risk) do not enter the expected-return determination. And firm characteristics are sufficient statistics for expected returns. I thus need not specify M_{t+1} — production-based asset pricing can in principle be developed independently from consumption-based asset pricing,

³For example, Chan, Jegadeesh, and Lakonishok (1996) and Haugen and Baker (1996) control for valuation ratios when they document the earnings momentum and profitability anomalies, respectively.

⁴Rubinstein (2001, p. 23) highlights the importance of analyzing corporate decisions in solving anomalies: “For the most part, financial economists take the stochastic process of stock prices, the value of the firms, or dividend payments as primitive. But to explain some anomalies, we may need to look deeper into the guts of corporate decision making to derive what the processes are.”

without being hindered by difficulties specific to the latter literature.

However, this practice only means that the effect of M_{t+1} is indirect, not irrelevant. For example, if M_{t+1} were a constant, M , then equation (14) implies that the expected return $E_t[r_{t+1}] = \frac{1}{M}$, a constant uncorrelated with firm characteristics. And if the correlation between M_{t+1} and X_{t+1} is zero, i.e., firms' operating profits are unaffected by aggregate shocks, then equation (14) implies that $E_t[r_{t+1}] = r_{ft}$, where $r_{ft} \equiv \frac{1}{E_t[M_{t+1}]}$ is risk-free rate. In this case, there is no cross-sectional variation in expected returns. The analysis below in effect provides time-series correlations between the risk-free rate and firm characteristics. Since I study expected returns directly, as opposed to expected excess returns, I need not restrict the correlation between M_{t+1} and X_{t+1} , the correlation that determines expected excess returns.

The characteristic-based approach is consistent with the traditional risk-based approach. From Proposition 2, $E_t[M_{t+1}r_{t+1}^S] = 1$. Following Cochrane (2001, p.19), I can rewrite this equation as the beta-representation, $E_t[r_{t+1}^S] = r_{ft} + \beta_t \lambda_{Mt}$, where $\beta_t \equiv \frac{-\text{Cov}_t[r_{t+1}^S, M_{t+1}]}{\text{Var}_t[M_{t+1}]}$ is the amount of risk, and $\lambda_{Mt} \equiv \frac{\text{Var}_t[M_{t+1}]}{E_t[M_{t+1}]}$ is the price of risk. Now Proposition 2 also says that $E_t[r_{t+1}^S] = E_t[r_{t+1}^I]$ where the right-hand side only depends on characteristics from equation (15). Further, $E_t[r_{t+1}^I] = E_t[r_{t+1}^S] = r_{ft} + \beta_t \lambda_{Mt}$, implies that $\beta_t = \frac{E_t[r_{t+1}^I] - r_{ft}}{\lambda_{Mt}}$, which ties covariances with characteristics. But apart from this mechanical link, risk only plays a secondary role in the characteristic-based determination of expected returns.

3.2 Intuition in Two Canonical Examples

I construct two canonical examples to illustrate the basic intuition underlying the anomalies explanations. Both examples have constant return to scale, $\alpha = 1$. In the first example, the only costs of investment are linear purchase/sale costs, i.e., $\Phi(I_t, K_t) = I_t$. And in the second

example, there are also quadratic costs of physical adjustment, i.e.,

$$\Phi(I_t, K_t) = I_t + \frac{a}{2} \left(\frac{I_t}{K_t} \right)^2 K_t \quad \text{where } a > 0 \quad (18)$$

3.2.1 Linear Purchase/Sale Costs

This example can explain the earnings-related anomalies. Intuitively, the marginal product of capital (i.e., MPK) at time $t+1$ is in the numerator of investment return. But MPK is closely related to profitability, so expected return increases with expected profitability.

Specifically, when $\Phi(I_t, K_t) = I_t$, equation (15) implies that:

$$\mathbf{E}_t[r_{t+1}] = \mathbf{E}_t[\Pi_1(K_{t+1}, X_{t+1})] + (1 - \delta) \quad (19)$$

i.e., expected net return is expected marginal product of capital minus depreciation rate.

Let $N_t \equiv \Pi_t - \delta K_t$ denote earnings. Equations (2) and (19) imply that:

$$\mathbf{E}_t[r_{t+1}] = \mathbf{E}_t \left[\frac{\Pi_{t+1}}{K_{t+1}} \right] + (1 - \delta) = \mathbf{E}_t \left[\frac{N_{t+1}}{K_{t+1}} \right] + 1 \quad (20)$$

i.e., expected return *is* expected profitability!

The example is also consistent with the profitability anomaly. Intuitively, profitability is highly persistent; therefore, high profitability implies high expected profitability, which in turn implies high expected returns. The following assumption captures this persistence:

Assumption 4 *The operating profit-to-capital ratio (or equivalently profitability) follows:*

$$\frac{\Pi_{t+1}}{K_{t+1}} = \bar{\pi}(1 - \rho_\pi) + \rho_\pi \left(\frac{\Pi_t}{K_t} \right) + \varepsilon_{t+1}^\pi \quad (21)$$

where $\bar{\pi} > 0$ and $0 < \rho_\pi < 1$ are the long-run average and the persistence of operating profit-to-capital, respectively. And ε_{t+1}^π is a normal random variable with a zero mean.

Since the operating profit-to-capital ratio equals profitability plus a constant depreciation rate, Assumption 4 basically says that profitability is persistent. Substituting $\Pi_t = N_t + \delta K_t$ into equation (21) yields:

$$\frac{N_{t+1}}{K_{t+1}} = (\bar{\pi} - \delta)(1 - \rho_\pi) + \rho_\pi \left(\frac{N_t}{K_t} \right) + \varepsilon_{t+1}^\pi \quad (22)$$

where the sum of the first two terms denotes expected profitability and ε_{t+1}^π denotes earnings surprise. There is much evidence on the persistence of profitability (e.g., Fama and French (1995, 2000, 2004)). In fact, Fama and French (2004) report that the current profitability is the strongest predictor of profitability one to three years ahead. It is important to note that the specific, first-order autoregressive form is unimportant, and more complex time series specifications will give basically the same economic insights.

Combining equations (20) and (21) yields:

$$E_t[r_{t+1}] = (\bar{\pi} - \delta)(1 - \rho_\pi) + \rho_\pi \left(\frac{N_t}{K_t} \right) + 1 \quad (23)$$

i.e., expected return is an increasing, linear function of profitability. Equation (23) also implies a new testable hypothesis, i.e., the magnitude of the profitability anomaly should increase with the persistence of profitability.

The same mechanism driving the expected-profitability and profitability anomalies is also useful for understanding the post-earnings-announcement drift that has bewildered financial economists for more than three decades. Intuitively, earnings surprise and profitability are both scaled earnings, and should contain similar information on future profitability.⁵ If

⁵To be precise, earnings surprise is commonly measured as Standardized Unexpected Earnings (SUE) (e.g., Chan, Jegadeesh, and Lakonishok (1996)). The SUE for stock i in month t is defined as $SUE_{it} \equiv \frac{e_{iq} - e_{iq-4}}{\sigma_{it}}$, where e_{iq} is quarterly earnings per share most recently announced as of month t for stock i , e_{iq-4} is earnings per share four quarters ago, and σ_{it} is the standard deviation of unexpected earnings, $e_{iq} - e_{iq-4}$, over the preceding eight quarters.

earnings surprise captures a principal component of expected profitability as profitability does, then earnings surprise should correlate positively with expected returns.

Formally, lagging equation (22) by one period and plugging the resulting $\frac{N_t}{K_t}$ into equation (23) yields $E_t[r_{t+1}] = (\bar{\pi} - \delta)(1 - \rho_\pi)(1 + \rho_\pi) + \rho_\pi^2 \frac{N_{t-1}}{K_{t-1}} + \rho_\pi \varepsilon_t^\pi + 1$. The equation implies that the expected return has a positive loading, ρ_π , on the current-period earnings surprise, ε_t^π . A new testable hypothesis emerges, i.e., the magnitude of the post-earnings announcement drift should increase with the persistence of profitability.

Although useful for explaining the sign of the earnings-related anomalies, the simple example with $\Phi(I_t, K_t) = I_t$ has many limitations. First, the inverse relation between the magnitude of the earnings-related anomalies and the market value cannot be explained. From equations (20) and (23), the partial derivatives of expected return with respect to expected profitability and profitability are both constant, independent of the market value. Second, the example cannot explain the value anomaly because $\Phi(I_t, K_t) = I_t$ implies that $Q_t = q_t = \Phi_1(I_t, K_t) = 1$, i.e., firms do not differ in market-to-book. Third, substituting $K_{t+1} = \left(\frac{I_t}{K_t} + (1 - \delta)\right) K_t$ into equation (20) and differentiating both sides yield $\frac{\partial E_t[r_{t+1}]}{\partial (I_t/K_t)} = E_t[\Pi_{11}(K_{t+1}, X_{t+1})]K_t = 0$, where the last equality follows from constant return to scale. This says that expected return is independent of the investment rate, and hence independent of the payout and equity-financing rates.

3.2.2 Quadratic Adjustment Costs

I now show that all the limitations in the first example can be extinguished by introducing adjustment costs into the model. To illustrate the basic intuition, I use a parametric example

with quadratic adjustment costs. Then equations (15) and (18) imply that:

$$r_{t+1} = \frac{\Pi_1(K_{t+1}, X_{t+1}) + (a/2)(I_{t+1}/K_{t+1})^2 + (1 - \delta)[1 + a(I_{t+1}/K_{t+1})]}{1 + a(I_t/K_t)} \quad (24)$$

This is in essence the same investment-return equation in Cochrane (1991, 1996).

The Expected-Profitability Anomaly Since $\Pi_1(K_{t+1}, X_{t+1}) = \frac{\Pi_{t+1}}{K_{t+1}} = \frac{N_{t+1}}{K_{t+1}} + \delta$, taking conditional expectations and differentiating both sides of equation (24) with respect to expected profitability yield $\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{1}{1+a(I_t/K_t)} > 0$.⁶ The inequality follows because the denominator equals the marginal q_t . Therefore, controlling for market-to-book (the denominator of investment return), expected return increases with expected profitability. Further, because the marginal q_t equals market-to-book from Proposition 1, $\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{1}{Q_t} = \frac{K_{t+1}}{P_t}$, which is inversely related with the market value, P_t . This explains why the magnitude of the expected-profitability anomaly is stronger in small firms.

The Profitability Anomaly From equation (21) and the chain rule, $\frac{\partial E_t[r_{t+1}]}{\partial (N_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} \frac{\partial E_t[N_{t+1}/K_{t+1}]}{\partial (N_t/K_t)} = \rho_\pi \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]}$. It then follows from the argument for the expected-profitability anomaly that $\frac{\partial E_t[r_{t+1}]}{\partial (N_t/K_t)}$ is positive and decreasing in the market value.

The Post-Earnings-Announcement Drift The argument for the profitability anomaly is useful for explaining the post-earnings-announcement drift because earnings surprise and profitability contain similar information on future profitability. The prediction that $\frac{\partial E_t[r_{t+1}]}{\partial (N_t/K_t)}$

⁶This partial derivative corresponds to the case of fixing $\frac{I_{t+1}}{K_{t+1}}$. This is only for the ease of exposition. Allowing $\frac{I_{t+1}}{K_{t+1}}$ to vary does not affect the qualitative result. The reason is that, intuitively, more profitable firms invest more, i.e., $\frac{\partial (I_{t+1}/K_{t+1})}{\partial E_t[N_{t+1}/K_{t+1}]} > 0$, consistent with the evidence in Fama and French (1995). As a result, the numerator of $\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]}$ remains positive. Formally, equations (10) and (21) imply that $\frac{\partial q_{t+1}}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{\rho_\pi}{r_{ft+1}}$ so $\frac{\partial (I_{t+1}/K_{t+1})}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{\partial (I_{t+1}/K_{t+1})}{\partial q_{t+1}} \frac{\partial q_{t+1}}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{1}{a} \frac{\rho_\pi}{r_{ft+1}} > 0$. And it follows that $\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{(1+\rho_\pi E_t[(1/r_{ft+1})(K_{t+2}/K_{t+1})])}{1+a(I_t/K_t)} > 0$.

decreases with the market value is particularly intriguing because the magnitude of the post-earnings-announcement drift is inversely related to the market value (e.g., Bernard (1993)).

I am not aware of other rational explanations of the earnings-related anomalies. Two papers offer explanations for a related anomaly, price momentum that buying recent winners and selling recent losers yield positive abnormal returns (e.g., Jegadeesh and Titman (1993)). In Berk, Green, and Naik (1999), the composition and systematic risk of the firm's assets are persistent, leading to positive autocorrelations of expected returns. In Johnson (2002), recent winners have temporarily higher expected growth than recent losers. Assuming that stocks with higher expected growth earn higher average returns, Johnson shows that his model can generate price momentum. I complement his work by showing that his key assumption arises naturally from the first principles of optimal investment.

The Investment Anomaly Intuitively, the Q -theory is a theory of investment demand. The downward-sloping investment-demand function then implies a negative relation between investment rate and cost of capital (i.e., expected return). Intuitively, investment rate increases with net present value of capital (e.g., Brealey and Myers (2003, Chapter 2)). But the net present value is inversely related to cost of capital, controlling for expected future cash flows. Higher cost of capital implies lower expected net present value, which in turn implies lower investment rate, and vice versa.

I now formally establish the negative slope of the investment-demand function, as in Figure 1. Let U_{t+1}^q denote the numerator of the investment return in equation (24), and $U_{t+1}^q > 0$. Taking conditional expectations and differentiating both sides with respect to $\frac{I_t}{K_t}$ yield: $\frac{\partial E_t[r_{t+1}]}{\partial (I_t/K_t)} = -\frac{aE_t[U_{t+1}^q]}{[1+a(I_t/K_t)]^2} + \frac{1}{1+a(I_t/K_t)} \frac{\partial E_t[U_{t+1}^q]}{\partial (I_t/K_t)}$. To show $\frac{\partial E_t[r_{t+1}]}{\partial (I_t/K_t)} < 0$, it then suffices to show $\frac{\partial E_t[U_{t+1}^q]}{\partial (I_t/K_t)} < 0$. But rewriting I_{t+1} and K_{t+1} in $E_t[U_{t+1}^q]$ as $K_{t+2} - (1-\delta) \left(\frac{I_t}{K_t} + (1-\delta) \right) K_t$

and $\left(\frac{I_t}{K_t} + (1 - \delta)\right) K_t$, respectively, and differentiating yield $\frac{\partial E_t[U_{t+1}^q]}{\partial(I_t/K_t)} = -\frac{aK_t(E_t[K_{t+2}])^2}{K_{t+1}^3} < 0$.⁷

From Figure 1, the investment-demand function is also convex. To see this, differentiating $\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)}$ once more with respect to $\frac{I_t}{K_t}$ yields $\frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)^2} = -\frac{a}{[1+a(I_t/K_t)]^2} \frac{\partial E_t[U_{t+1}^q]}{\partial(I_t/K_t)} + \frac{2a^2 E_t[U_{t+1}^q]}{[1+a(I_t/K_t)]^3} + \frac{1}{1+a(I_t/K_t)} \frac{\partial^2 E_t[U_{t+1}^q]}{\partial(I_t/K_t)^2} - \frac{\partial E_t[U_{t+1}^q]}{\partial(I_t/K_t)} \frac{a}{[1+a(I_t/K_t)]^2} > 0$, where the inequality follows from $\frac{\partial E_t[U_{t+1}^q]}{\partial(I_t/K_t)} < 0$ and $\frac{\partial^2 E_t[U_{t+1}^q]}{\partial(I_t/K_t)^2} = \frac{3aK_t^2(E_t[K_{t+2}])^2}{K_{t+1}^4} > 0$. Later I use this convexity to understand other evidence.

The investment anomaly is stronger in firms with high operating income-to-asset ratios (e.g., Titman, Wei, and Xie (2003)). This pattern can be captured in the model. Using equation (21) to express $\frac{\Pi_{t+1}}{K_{t+1}}$ in terms of $\frac{\Pi_t}{K_t}$ and differentiating $-\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)}$ with respect to $\frac{\Pi_t}{K_t}$ yields $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right| / \partial \left(\frac{\Pi_t}{K_t} \right) = \frac{a\rho\pi}{[1+a(I_t/K_t)]^2} > 0$.

Besides Cochrane (1991, 1996), most models cited in footnote 1 can explain the investment anomaly. I contribute by unifying their diverse explanations with the investment-return equation, by using it to explain other anomalies, and by illustrating the interaction between the return-investment relation and operating income-to-capital.

The Value Anomaly The downward-sloping and convex investment-demand function manifests itself as many anomalies other than the investment anomaly. The value anomaly can be explained using the investment-demand function. From the optimality condition (8), $1+a\frac{I_t}{K_t} = q_t = Q_t$, so $\frac{\partial(I_t/K_t)}{\partial Q_t} = \frac{1}{a} > 0$. This says that growth firms invest more and grow faster than value firms, a result consistent with the evidence in Fama and French (1995). The chain rule of partial derivatives then implies that $\frac{\partial E_t[r_{t+1}]}{\partial Q_t} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial Q_t} < 0$, i.e., growth firms earn lower average returns than value firms.

The value anomaly is also stronger in small firms. To see this, again by the chain rule, $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \right| / \partial P_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} = -\frac{1}{a} \frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)^2} \frac{\partial(I_t/K_t)}{\partial P_t}$. To show that the left-hand side is

⁷I have used the Leibniz integral rule to change the order of integration and differentiation.

negative, it suffices to show $\frac{\partial(I_t/K_t)}{\partial P_t} > 0$ because the investment-demand function is convex.

But from $1 + a\frac{I_t}{K_t} = q_t = Q_t = \frac{P_t}{K_{t+1}}$, $P_t = \left[1 + a\frac{I_t}{K_t}\right] \left[\frac{I_t}{K_t} + (1 - \delta)\right] K_t$. Differentiating both sides with respect to $\frac{I_t}{K_t}$ yields $\frac{\partial P_t}{\partial(I_t/K_t)} = q_t K_t + a K_{t+1} > 0$.⁸

Several recent studies have proposed rational explanations for the value anomaly using investment-based models. Berk, Green, and Naik (1999) construct a real options model in which endogenous changes in assets in place and in growth options impart predictability in returns. Also using real options models, Carlson, Fisher, and Giammarino (2004a) emphasize the role of operating leverage, and Cooper (2005) emphasize the role of fixed costs in driving the value anomaly. Gomes, Kogan, and Zhang (2003) use a dynamic general equilibrium production economy, Kogan (2004) uses a two-sector general equilibrium model, and Zhang (2005) uses a neoclassical investment model to link expected returns to firm characteristics.

My model is most related to Zhang (2005). By making Assumptions 1–3, I now obtain some analytical results. The scope of anomalies addressed is also much wider. Zhang offers an explicitly solved model in which Assumption 3 is violated. And his simulation results are consistent with my analytical results. This consistency implies that, even when stock and investment returns are not exactly equal without Assumption 3, they share similar time-series and cross-sectional properties.

More recently, Gourio (2004) analyzes a putty-clay investment model. He argues that imperfect capital-labor substitutability can induce more than one percent increase in operating profits given a one percent increase in sales. And this effect is more important

⁸ $\frac{\partial P_t}{\partial(I_t/K_t)} > 0$ and $\frac{\partial Q_t}{\partial(I_t/K_t)} > 0$ both imply that growth firms invest more and grow faster. $\frac{\partial P_t}{\partial(I_t/K_t)} > 0$ does not contradict the evidence that small firms invest more and grow faster than big firms (e.g., Evans (1987) and Hall (1987)). The evidence is documented with the logarithm of employment as the measure of firm size. This measure corresponds to $\log(K_t)$ in the model. The model is consistent with the evidence because $P_t = \left[1 + a\frac{I_t}{K_t}\right] \left[\frac{I_t}{K_t} + (1 - \delta)\right] K_t$ implies that $K_t = P_t \left(\left[1 + a\frac{I_t}{K_t}\right] \left[\frac{I_t}{K_t} + (1 - \delta)\right]\right)^{-1}$, which in turn implies that $\frac{\partial K_t}{\partial(I_t/K_t)} < 0$.

for value firms because they have low productivity. Finally, like my work, Chen (2004) also explains the inverse relation between the value anomaly and the market value. Chen argues that the inverse relation arises from shorter life expectancy of small firms. This mechanism is different from mine that arises from convex adjustment cost and applies to long-lived firms.

The Payout Anomaly The payout anomaly can also be explained using the investment-demand function. Intuitively, firms' cash-flow constraint says that the sources and the uses of funds must be equal. With quadratic adjustment costs, when free cash flow $C_t > 0$, this constraint is $\frac{C_t}{K_t} = \frac{\Pi_t}{K_t} - \frac{I_t}{K_t} - \frac{a}{2} \left(\frac{I_t}{K_t} \right)^2$. As a result, $\frac{\partial(C_t/K_t)}{\partial(I_t/K_t)} = - \left(1 + a \frac{I_t}{K_t} \right) = -q_t < 0$. Thus, controlling for profitability, optimal payout and investment rates are negatively correlated. Grullon, Michaely, and Swaminathan (2002) document that dividend-increasing firms significantly reduce their capital expenditures over the next three years, while the dividend-decreasing firms begin to increase their capital expenditure. By the chain rule, the negative slope of the investment-demand function then manifests itself as the positive expected return-payout relation (i.e., $\frac{\partial E_t[r_{t+1}]}{\partial(C_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(C_t/K_t)} > 0$). And the convexity of the investment-demand function manifests itself as the stronger payout anomaly in value firms (i.e., $\frac{\partial^2 E_t[r_{t+1}]}{\partial(C_t/K_t)\partial Q_t} = \frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)^2} \frac{\partial(I_t/K_t)}{\partial Q_t} \frac{\partial(I_t/K_t)}{\partial(C_t/K_t)} < 0$).

I am not aware of other rational explanations for the payout anomaly.

The SEO-Underperformance Anomaly This anomaly can also be explained using the investment-demand function. Intuitively, firms' cash-flow constraint says that the sources and the uses of funds must be equal. With quadratic adjustment costs, when outside equity $O_t > 0$, this constraint is $\frac{O_t}{K_t} = \frac{I_t}{K_t} + \frac{a}{2} \left(\frac{I_t}{K_t} \right)^2 - \frac{\Pi_t}{K_t}$. As a result, $\frac{\partial(O_t/K_t)}{\partial(I_t/K_t)} = q_t > 0$. Thus, controlling for profitability, optimal equity-financing and investment rates are positively

correlated. By the chain rule, the negative slope of the investment-demand function then manifests itself as the negative expected return-financing relation (i.e., $\frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} < 0$). And the convexity of the investment-demand function manifests itself as the stronger SEO-underperformance in small firms (i.e., $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} \right| / \partial P_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial(O_t/K_t)\partial P_t} = -\frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)^2} \frac{\partial(I_t/K_t)}{\partial P_t} \frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} - \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial^2(I_t/K_t)}{\partial P_t \partial(O_t/K_t)} < 0$). The last inequality follows because $\frac{\partial(O_t/K_t)}{\partial(I_t/K_t)} = q_t = Q_t = \frac{P_t}{K_{t+1}}$ implies that $\frac{\partial^2(I_t/K_t)}{\partial(O_t/K_t)\partial P_t} = -\frac{K_{t+1}}{P_t^2} < 0$.

Loughran and Ritter (1997) and Richardson and Sloan (2003) provide some evidence supportive of the Q -explanation of the SEO anomaly. Loughran and Ritter shows that issuing firms have much higher investment rates than nonissuing firms for nine years around the issuing date. And issuing firms are disproportionately high-growth firms. Richardson and Sloan find that the negative relation between external finance and expected returns varies systematically with the use of the proceeds. When the proceeds are invested in net operating assets as opposed to being stored as cash, the negative relation is stronger. In contrast, the negative relation is much weaker when the proceeds are used for refinancing or retained as cash. This evidence suggests an important role of capital investment in driving the SEO anomaly. And this is exactly my theoretical approach.

The model shows that the stronger value anomaly in small firms and the stronger SEO anomaly in small firms are basically the same phenomenon driven by the convex expected return-investment relation. This prediction is consistent with the evidence that the SEO underperformance shrinks greatly once both size and book-to-market are controlled for (e.g., Brav, Geczy, and Gompers (2000) and Eckbo, Masulis, and Norli (2000)).

Several recent studies have proposed rational explanations of the SEO anomaly. Eckbo, Masulis, and Norli (2000) argue that issuing firms are less risky because their leverage ratios

are lowered. There is no leverage in my model, and the economic mechanism works through optimal investment. Schultz (2003) argues that using event studies is likely to find negative abnormal performance ex post, even if there is no abnormal performance ex ante.⁹ The calendar-time evidence is immune to this problem. But the Q -explanation applies to event-time and calendar-time underperformance.

Carlson, Fisher, and Giammarino (2004b) argue that that prior to issuance, the firm has both assets in place and an option to expand; this composition is a levered, risky position. If the exercise of the option is financed by equity issuance, then risk must drop afterwards. The real options explanation and the Q -explanation are consistent because they both work through optimal investment. But I do not assume growth options to be riskier than assets in place, although it is likely to be true in good times when the option to expand is important.

3.3 The General Model

I now extend the results in the previous two examples into the general Q -theoretical framework. This is an important step because the general setup allows much more flexible econometric specifications than the quadratic adjustment-cost function. Except for a few technical details, the basic intuition remains unchanged in the general setup.

Proposition 3 (*The Expected-Profitability Anomaly*) *Under Assumptions 1 and 3, expected returns correlate positively with expected profitability, $\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} > 0$, and the magnitude of the correlation decreases with the market value, $\frac{\partial^2 E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}] \partial P_t} < 0$.*

⁹Schultz (2003) uses his argument to explain the underperformance of initial public offerings (IPOs). The same logic applies to SEOs. If early in a sample period, SEOs underperform, there will be few SEOs in the future because investors are less interested in them. The average performance will be weighted more towards the early SEOs that underperformed. If early SEOs outperform, there will be many more SEOs in the future. The early performance will be weighted less in the average performance. Weighting each period equally as in calendar-time regressions solves this problem.

Proposition 4 (The Profitability Anomaly) Under Assumptions 1–4, expected returns correlate positively with current-period profitability, and the magnitude of this correlation decreases with the market value, i.e., $\frac{\partial E_t[r_{t+1}]}{\partial(N_t/K_t)} > 0$ and $\frac{\partial^2 E_t[r_{t+1}]}{\partial(N_t/K_t)\partial P_t} < 0$.

Proposition 5 (The Post-Earnings-Announcement Drift) Under Assumptions 1–4, expected returns correlate positively with current-period earnings surprise, and the magnitude of this correlation decreases with the market value, i.e., $\frac{\partial E_t[r_{t+1}]}{\partial \varepsilon_t^\pi} > 0$ and $\frac{\partial^2 E_t[r_{t+1}]}{\partial \varepsilon_t^\pi \partial P_t} < 0$.

Proposition 6 (The Investment Anomaly) Under Assumptions 1–3, expected returns decrease with investment rate: $\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} < 0$. If Assumption 4 also holds, the magnitude of the investment anomaly increases with operating profit-to-asset: $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right| / \partial \left(\frac{\Pi_t}{K_t} \right) > 0$.

Cochrane (1991, 1996) uses models with quadratic adjustment costs to derive the negative relation between expected return and investment rate. He also shows that the relation between expected return and expected investment rate and the relation between expected return and expected investment growth are both positive. I extend his argument into the general Q -framework, and use it as a foundation to explain other anomalies.

To derive the positive relations of expected returns with expected investment rate and expected investment growth, note that equations (4) and (15) implies that $\frac{\partial E_t[r_{t+1}]}{\partial(I_{t+1}/K_{t+1})} = \frac{K_{t+1}^{\alpha-1}}{q_t} E_t \left[(1-\alpha)G' \left(\frac{I_{t+1}}{K_{t+1}} \right) + G'' \left(\frac{I_{t+1}}{K_{t+1}} \right) \frac{K_{t+2}}{K_{t+1}} \right] > 0$. The inequality follows because $1-\alpha \geq 0$, $\frac{K_{t+2}}{K_{t+1}} > 0$, and $G'' > 0$. Given that expected return decreases with $\frac{I_t}{K_t}$ but increases with $\frac{I_{t+1}}{K_{t+1}}$, it should also increase with $\frac{I_{t+1}}{K_{t+1}} / \frac{I_t}{K_t}$. But as a ratio of two stock variables, $\frac{K_t}{K_{t+1}}$ is likely to be dominated by the ratio of two flow variables, $\frac{I_{t+1}}{I_t}$. Therefore, expected return should increase with expected investment growth.

In the general model, the investment rate is an increasing function of marginal q . Equation (8) implies that $G' \left(\frac{I_t}{K_t} \right) K_t^{\alpha-1} = q_t$ or $\frac{I_t}{K_t} = G'^{-1}(q_t K_t^{1-\alpha})$, where $G'^{-1}(\cdot)$ is the

inverse function of $G'(\cdot)$. And since $G'' > 0$, both $G'(\cdot)$ and $G'^{-1}(\cdot)$ are increasing functions. Because marginal q is proportional to market-to-book, the negative slope of the investment-demand function implies the negative relation between expected return and market-to-book.

To explain why the value anomaly is stronger in small firms, I need:

Assumption 5 *The augmented adjustment-cost function $\Phi(I_t, K_t)$ satisfies:*

$$\Phi_{111}(I_t, K_t) \geq 0; \quad \Phi_{112}(I_t, K_t) \leq 0; \quad \text{and} \quad \Phi_{222}(I_t, K_t) \leq 0$$

It is easy to verify that standard specifications such as the quadratic adjustment-cost function and the proportional and quadratic financing-cost functions satisfy this assumption.

Proposition 7 (The Value Anomaly) *Under Assumptions 1–3, expected returns correlate negatively with market-to-book, $\frac{\partial E_t[r_{t+1}]}{\partial Q_t} < 0$. If Assumption 5 also holds, the magnitude of this correlation decreases in the market value, $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \right| / \partial P_t < 0$.*

Some new testable hypotheses are collected below.

Proposition 8 *Under Assumptions 1–3 and 5: (i) the relation between expected return and market-to-book is convex, $\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} > 0$; (ii) the investment anomaly is stronger in small firms, $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial (I_t/K_t)} \right| / \partial P_t < 0$; and (iii) the investment anomaly is stronger in value firms., $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial (I_t/K_t)} \right| / \partial Q_t < 0$. If $2 \left[G'' \left(\frac{I_t}{K_t} \right) \right]^2 \geq G''' \left(\frac{I_t}{K_t} \right) G' \left(\frac{I_t}{K_t} \right)$ also holds, then (iv) the investment-demand function is convex, i.e., $\frac{\partial^2 E_t[r_{t+1}]}{\partial (I_t/K_t)^2} > 0$.*

Proposition 8 says that the convexity in the investment-demand function holds in the general model only if $2 \left[G'' \left(\frac{I_t}{K_t} \right) \right]^2 \geq G''' \left(\frac{I_t}{K_t} \right) G' \left(\frac{I_t}{K_t} \right)$. Although compatible with quadratic adjustment costs, this condition is more strict than the other assumptions.

In the general model, firms' cash-flow constraint becomes $\frac{C_t}{K_t} = \frac{\Pi_t}{K_t} - G\left(\frac{I_t}{K_t}\right) K_t^{\alpha-1}$ when payout $C_t > 0$. Controlling for profitability, optimal payout and investment rates are again negatively correlated. This negative correlation, coupled with the downward-sloping investment-demand function, implies a positive expected return-payout relation. And by the chain rule, the convexity of the relation between expected return and market-to-book gives rise to the stronger payout anomaly in value firms.

Proposition 9 (*The Payout Anomaly*) Denote payout or free cash flow as:

$$C_t \equiv C(K_t, K_{t+1}, X_t) = (\Pi(K_t, X_t) - \Phi(I_t, K_t)) \mathbf{1}_{\{\Pi(K_t, X_t) - \Phi(I_t, K_t) > 0\}} \quad (25)$$

where $\mathbf{1}_{\{\cdot\}}$ is an indicator function that takes the value of one if the event described in $\{\cdot\}$ is true and zero otherwise. Under Assumptions 1–3, expected returns increase weakly with the payout rate, $\frac{C_t}{K_t}$, i.e., $\frac{\partial E_t[r_{t+1}]}{\partial (C_t/K_t)} \geq 0$, where the inequality is strict when C_t is strictly positive. If Assumption 5 also holds, the payout anomaly is stronger in value firms than that in growth firms, $\frac{\partial^2 E_t[r_{t+1}]}{\partial (C_t/K_t) \partial Q_t} \leq 0$, where the inequality is strict when $C_t > 0$.

Firms' cash-flow constraint is $\frac{O_t}{K_t} = G\left(\frac{I_t}{K_t}\right) K_t^{\alpha-1} - \frac{\Pi_t}{K_t}$ when outside equity $O_t > 0$. Controlling for profitability, optimal financing and investment rates are positively correlated. This correlation, coupled with the downward-sloping investment-demand function, implies a negative expected return-financing relation. By the chain rule, the convex relation between expected return and market-to-book implies the stronger SEO anomaly in small firms.

Proposition 10 (*The SEO Anomaly*) Denote the outside equity, O_t , as:

$$O_t \equiv O(K_t, K_{t+1}, X_t) = (\Phi(I_t, K_t) - \Pi(K_t, X_t)) \mathbf{1}_{\{\Phi(I_t, K_t) - \Pi(K_t, X_t) > 0\}} \quad (26)$$

Under Assumptions 1 and 3, expected returns decrease weakly with the rate of external or

outside equity, $\frac{O_t}{K_t}$, i.e., $\frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} \leq 0$, where the inequality is strict when O_t is strictly positive.

If Assumption 5 also holds, the magnitude of this correlation is stronger in small firms,

$\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} \right| / \partial P_t \leq 0$, where the inequality is strict when $O_t > 0$.

4 Empirical Implications

This section discusses empirical implications of the theoretical results. Section 4.1 proposes the Q -representation of expected returns as a new empirical asset pricing model. Sections 4.2, 4.3, and 4.4 compare the Q -framework with the standard beta- and SDF-framework as well as the Ohlson (1995) valuation model popular in accounting research, respectively. I argue that, although internally consistent with the existing frameworks in theory, the Q -framework is likely to have comparative advantages in practice.

4.1 A New Empirical Asset Pricing Model

By Proposition 2, if the operating-profit and the augmented adjustment-cost functions have the same degree of homogeneity, stock return equals investment return. Ex ante, this implies that expected stock returns equal expected investment returns.

This ex ante restriction can be tested using the following moment conditions:

$$E \left[\left(r_{t+1}^S - \frac{\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}) + (1 - \delta)\Phi_1(I_{t+1}, K_{t+1}))}{\Phi_1(I_t, K_t)} \right) \otimes \mathbf{Z}_t \right] = 0 \quad (27)$$

where \mathbf{Z}_t is a vector of instrumental variables known at time t , such as anomaly-related variables. r_{t+1}^S is the stock returns of portfolios sorted by the anomaly-related variables. Φ can be properly parameterized, as in the investment literature (e.g., Hubbard (1998) and Erickson and Whited (2000)). With the estimated parameters, expected stock returns can

be constructed from economic fundamentals through the expected investment returns.¹⁰

Other aspects of the real economy, such as financial constraints and labor adjustment costs, can be incorporated into the investment-return equation. And empire-building type of agency cost can be introduced by assuming managers derive private benefits proportional to the operating profit (e.g., Stulz (1990)). At the portfolio level, convex costs of adjustment are perhaps enough because investment at this disaggregated level is smooth. At the firm level, where lumpy investment is common (e.g., Doms and Dunne (1998)), non-convex costs can be introduced, such as the wedge between purchase and sale prices of capital and fixed costs proportional to capital.

4.2 The Q -Framework versus the Beta-Framework

The beta-framework is very popular in empirical finance. In event studies, cumulative abnormal returns are computed as the difference between realized returns and expected returns from, for example, the CAPM. Tests are performed to see if cumulative abnormal returns are on average zero (e.g., Ball and Brown (1968) and Fama, Fisher, Jensen, and Roll (1969)). In cross-sectional tests, stock returns are regressed on beta and firm characteristics (e.g., Fama and French (1992)). In time-series tests, mimicking portfolios are formed based on characteristics of interest. Their average returns are tested to see if they equal zero, and zero-intercept tests are performed by regressing the portfolio returns on a set of benchmark factor returns (e.g., Fama and French (1993)).

The null hypotheses in these tests are derived from the CAPM and its various extensions, either static or conditional, single-factor or multi-factor models. Similar to the CAPM,

¹⁰Cochrane (1991) implicitly tests the moment condition (27) by comparing the properties of stock and investment returns, both at the aggregate level.

all these extensions say that only covariances should explain expected returns. Anomalies emerge because characteristics often dominate covariances in explaining returns. That only covariances matter is the basic point of Daniel and Titman (1997), and is taken as “one general feature of the rational approach” in Barberis and Thaler (2003, p. 1091).

Not necessarily. My results show that characteristics can affect expected returns, often in the directions reported in the anomalies literature. But my model is entirely rational. Therefore, the empirical debate on covariances versus characteristics is not a well-defined question. And rejecting the CAPM and its close cousins is not equivalent to rejecting efficient markets (e.g., Fama (1965)) or rational expectations (e.g., Muth (1961) and Lucas (1972)).

Further, the Q -representation is perhaps more useful in practice than the beta-representation. The reason is that the right-hand side of the Q -representation contains only firm characteristics. And measuring characteristics basically amounts to loading and cleaning data from Compustat, much easier than measuring covariances.

Measuring covariances is difficult. First, consumption-based asset pricing has not settled on the right form of the SDF, with which returns are supposed to covary. Second, all dynamic models imply that covariances are time-varying. But despite recent theoretical efforts, no easy-to-implement econometric specifications have been derived. And estimates of time-varying covariances in practice often use convenient, but ad hoc specifications yielding results sensitive to alternative methods. Finally, even if we assume the priced common factors are known and covariances are constant, estimates of expected returns from beta-pricing models are extremely imprecise even at the industry level (e.g., Fama and French (1997)).

The difficulty of measuring covariances is illustrated vividly in Berk, Green, and Naik (1999) and Gomes, Kogan, and Zhang (2003). In these models, covariances are sufficient

statistics of expected returns. And true covariances indeed dominate characteristics in cross-sectional regressions in their simulations. But when estimated covariances are used, they are dominated by characteristics. Unfortunately, true covariances are unobservable in practice.

In sum, it is perhaps time to explore alternative empirical models of expected returns, for example, along the lines of the Q -representation, without having to estimate covariances.

4.3 The Q -Framework versus the SDF-Framework

The Q -framework complements the SDF-framework that is the workhorse of consumption-based asset pricing (e.g., Cochrane (2001) and Campbell (2003)).

Tests under the SDF-framework are usually done by using $E_t[M_{t+1}r_{t+1}^S] = 1$ as moment conditions in GMM, where M_{t+1} is the SDF that can be parameterized using aggregate consumption (e.g., Hansen and Singleton (1982)). This framework has had some success in understanding anomalies (e.g., Lettau and Ludvigson (2001), Lustig and Nieuwerburgh (2004), Parker and Julliard (2004), and Piazzesi, Schneider, and Tuzel (2004)).

But the SDF-framework still leaves plenty of room open. Most important, anomalies are empirical relations between expected returns and firm characteristics. But characteristics do not enter the moment conditions directly. They are buried in r_{t+1}^S , i.e., portfolio returns sorted on characteristics. Further, even if the moment conditions survive over-identification tests, it is not clear what economic mechanisms drive the results. For example, the empirical success of Lettau and Ludvigson (2001) and Lustig and Nieuwerburgh (2004) relies on the returns of value stocks covarying more with the price of risk in bad times than the returns of growth stocks. But why this occurs can perhaps be better understood by modeling expected returns and firm characteristics together, for example, in the Q -theoretical framework.

For another example, the important contributions of Bansal, Dittmar, and Lundblad (2004) and Campbell and Vuolteenaho (2004) show that the value anomaly can be explained because value stocks have higher cash-flow betas than growth stocks. But the underlying economic mechanism is unknown because firm dynamics are not modeled.

Characteristics do enter the SDF framework directly in Cochrane (1996), Gomes, Yaron, and Zhang (2004), and Whited and Wu (2004). In Cochrane and Gomes et al., the SDF is a linear function of aggregate investment return constructed using aggregate fundamentals. But firm characteristics are absent. White and Wu test $E_t[M_{t+1}r_{t+1}^I] = 1$ where M_{t+1} is a linear combination of the Fama-French (1993) factors. Firm characteristics show up in constructing firm-level investment returns, r_{t+1}^I . But stock returns are now absent.

In all, by linking expected returns directly to characteristics in a rigorous, yet easy-to-implement framework, the Q -theory can cover the grounds missing from the SDF framework. In terms of the big picture, Fama (1991, p. 1610) calls for a coherent story that “(1) relates the cross-section properties of expected returns to the variation of expected returns through time, and (2) relates the behavior of expected returns to the real economy in a rather detailed way”. Consumption-based asset pricing is naturally fit for the first goal, but production-based asset pricing is perhaps better equipped to achieve the second. And the coherent story envisioned by Fama can be provided by the conceptual framework of general equilibrium.

4.4 The Q -framework versus the Ohlson Framework

The Q -framework is also related to Ohlson’s (1995) residual income valuation model that is extremely popular in capital markets research in accounting (e.g., Frankel and Lee (1998), Dechow, Hutton, and Sloan (1999), and Kothari (2001)).

The valuation model says that:

$$\frac{P_t}{B_t} = 1 + \frac{\sum_{j=1}^{\infty} E[Y_{t+j} - rB_{t+j-1}]/(1+r)^j}{B_t} \quad (28)$$

where B_t is book equity at time t , Y_{t+j} is earnings at $t+j$, $Y_{t+j} - rB_{t+j-1}$ is the residual income, defined as the difference between earnings and the opportunity cost of capital, and r is the discount rate for the expected residual income or the long-term expected stock return.

The model has several predictions.¹¹ First, controlling for expected residual earnings and expected book equity relative to current book equity, a higher book-to-market equity implies a higher expected return. Second, given book-to-market, firms with higher expected residual income relative to current book equity have higher expected returns. Third, controlling for book-to-market and the expected growth in book equity or investment growth, more profitable firms or firms with higher expected earnings relative to current book equity have higher expected returns. Finally, given book-to-market and expected profitability, firms with higher expected growth in book equity have lower expected returns.

These predictions are largely consistent with the predictions of the Q -model, implying that the Q -model is potentially useful in guiding empirical capital markets research.

But there is one notable difference. The Ohlson model says that high expected investment growth leads to low expected returns, but the Q -model says otherwise. Liu, Warner, and Zhang (2003) find that firms with higher expected investment growth earn higher average returns than firms with lower expected investment growth, but the average-return difference is only marginally significant. Further tests can sort out these two competing hypotheses.

Several recent papers use valuation models to estimate expected returns (e.g., Claus and

¹¹The discussion on the predictions from the Ohlson model follows that of Fama and French (2004).

Thomas (2001) and Gebhardt, Lee, and Swaminathan (2001)). They find that the estimated equity premium is only about 2–3%, much lower than the historical average. Kothari (2001) argues that their long-term growth forecasts, especially the terminal perpetuity growth rates, seem too low. In contrast, estimating expected returns from the Q -model only requires inputs of the one-period-ahead profitability and investment rate, which should be easier to forecast than their long-term counterparts.

More important, valuation models are accounting models. In contrast, based on the first principles, the Q -theory can provide a microeconomic foundation that links expected returns to the real economy in a rather detailed way.

5 Conclusion

A voluminous literature on capital markets anomalies in financial economics has mounted an enormous challenge to efficient markets with rational expectations. These anomalies are empirical relations of future stock returns with firm characteristics, corporate policies, and events, relations not predicted by current rational asset pricing theories.

Using a neoclassical model, I demonstrate analytically that, much like aggregate expected returns that vary with business cycles (e.g., Campbell and Cochrane (1999)), expected returns in the cross-section vary with firm characteristics, corporate policies, and events. Accordingly, the model is qualitatively consistent with many anomalies often interpreted as over- and under-reaction in inefficient markets. These anomalies include the relations of future stock returns with market-to-book, investment and disinvestment rates, seasoned equity offerings, tender offers and stock repurchases, dividend omissions and initiations, expected profitability, profitability, and more important, earnings announcement. The model

also implies a new empirical asset pricing model that avoids the difficult task of estimating covariances and long-term growth rates.

The basic point of this paper is reminiscent in spirit of the point made by Kydland and Prescott (1982). The Kydland-Prescott paper says that the neoclassical framework is a good start to build an equilibrium theory of business cycles. Monetary misperceptions and sticky prices from Keynesian economics may be important, but their effects can be better quantified and hence understood using the neoclassical benchmark. Similarly, this paper says that the neoclassical framework is a good start to build an equilibrium theory of the cross-section of returns. Over- and under-reaction from behavioral finance may be important, but their effects can be better quantified and hence understood using the neoclassical benchmark.

From this perspective, I view my theoretical work as complementary to behavioral theories of Barberis, Shleifer, and Vishny (1998), Daniel, Hirshleifer, and Subramanyam (1998), and Hong and Stein (1999). In explaining anomalies, these models assume constant expected returns and focus on systematic variations in abnormal returns. By constructing an economic foundation for time-varying expected returns in the cross section, I provide a rational benchmark against which the importance of investor sentiment can be gauged.

The equilibrium analysis of the cross section of returns has only started. Much more work remains to be done. The Q -theory can be extended to model IPO, mergers and acquisitions, spinoffs, debt-financing, and other corporate decisions. We can then evaluate whether the theory is consistent with long-term stock price drift associated with these events. Numerically solved models are also valuable for producing richer economic insights (for example, cyclical variation of equity financing) than those available analytically. To obtain quantitative predictions, computational experiments can be implemented in the style of Kydland and

Prescott (1982). Finally, several authors have used the real options framework to explain anomalies (e.g., Berk, Green, and Naik (1999) and Carlson, Fisher, and Giammarino (2004a, 2004b)). It is interesting to work out the interrelations between the Q -based and the real options-based explanations. To this end, a framework similar to that of Abel, Dixit, Eberly, and Pindyck (1996) can be useful.

More important, the Q -representation of expected returns can be implemented empirically to see to what extent the economic mechanisms identified in this paper can explain the anomalies quantitatively. More direct tests are also available. We can measure earnings momentum after controlling for the pricing effects of expected profitability or profitability. Further, the Q -theory implies that the investment, value, payout, and SEO anomalies are basically the same phenomenon driven by optimal investment. It is interesting to measure how much payout and SEO anomalies subsist after controlling for capital investment.

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A Anomalies

This appendix briefly reviews the empirical literature on the anomalies that are the targets of my theoretical explanations in this paper.

The Investment Anomaly Disinvesting firms earn higher average returns (e.g., Miles and Rosenfeld (1983), Cusatis, Miles, and Woolridge (1993)), but investing firm earn lower average returns in the future (e.g., Richardson and Sloan (2003), Titman, Wei, and Xie (2003), Anderson and Garcia-Feijóo (2004), and Xing (2004)). Titman et al. also shows that the anomaly is stronger for firms with higher operating income-to-asset ratios. Cusatis et al. attribute their evidence to market underreaction. Richardson and Sloan and Titman et al. interpret their evidence as investors underreacting to empire-building implications of capital investment. Anderson and Garcia-Feijóo interpret their evidence as consistent with the real options models of Berk, Green, and Naik (1999) and Gomes, Kogan, and Zhang (2003). Xing interprets her evidence using an optimal investment model similar to that in Zhang (2004).

The Value Anomaly Value stocks earn higher average returns than growth stocks (e.g., Graham and Dodd (1934), Rosenberg, Reid, and Lanstein (1985), Fama and French (1992), and Lakonishok, Shleifer, and Vishny (1994)). Fama and French (1993) also document that the value anomaly is stronger in small firms than in big firms where firm size is measured as the ex-dividend market value.

The Payout Anomaly Anomalous long-term positive abnormal returns apply to firms paying cash-flow out to shareholders, and are often interpreted as underreaction. Lakonishok and Vermaelen (1990) find positive long-term abnormal returns when firms tender for their stocks. Ikenberry, Lakonishok, and Vermaelen (1995) find that the average abnormal four-year return after the announcements of open market share repurchases is significantly positive. And the average abnormal return is much higher for value firms, but is negative although insignificant for growth firms. Finally, Michaely, Thaler, and Womack (1995) find that stock prices underreact to the negative information in dividend omissions and the positive information in initiations.

The SEO-Underperformance Anomaly Anomalous long-term negative abnormal returns apply to firms raising capital from external markets, and are often interpreted as overreaction. Loughran and Ritter (1995) and Spiess and Affleck-Graves (1995) document that firms conducting seasoned equity offerings (SEO) earn much lower returns over the next three to five years than nonissuing firms with similar characteristics. Brav, Geczy, and Gompers (2000) and Eckbo, Masulis, and Norli (2000) find that the underperformance is more pronounced for small firms. A frequent conclusion in this literature is that firms time their external financing decisions to exploit the mispricing of their securities in capital markets because of investor overreaction (e.g., Ritter (2003)).

The Expected-Profitability Anomaly Stock prices “underreact” to new information about future cash flow. Shocks to expected cash flows are positively correlated with shocks to expected returns (e.g., Frankel and Lee (1998), Dechow, Hutton, and Sloan (1999), Cohen, Gompers, and Vuolteenaho (2002), Vuolteenaho (2002), and Fama and French (2004)). Lettau and Ludvigson (2004) find similar evidence at the aggregate level. Cohen et al. and Vuolteenaho also find that the magnitude of this correlation is higher in small firms.

The Profitability Anomaly Given market price relative to cash flows or book equity, more profitable firms earn higher average returns (e.g., Haugen and Baker (1996) and Piotroski (2000)). Piotroski also shows that this relation is stronger in small firms.

The Post-Earnings-Announcement Drift Ball and Brown (1968) and Bernard and Thomas (1989, 1990) document that stock price drifts in the direction of earnings surprise, defined as the scaled change in earnings. Bernard (1993) shows that the magnitude of the drift is inversely related to the market value. And Chan, Jegadeesh, and Lakonishok (1996) find similar evidence using time series and cross-sectional regressions. This anomaly is often interpreted as underreaction to earnings news.

B Proofs

Proof of Lemma 1 By the Principle of Optimality (e.g., Theorem 9.2 of Stokey, Lucas, and Prescott (1989)), the firm’s value function (6) can be rewritten recursively as:

$$V(K_t, X_t) = \max_{K_{t+1}} \Pi(K_t, X_t) - \Psi(K_t, K_{t+1}) + E_t[M_{t+1}V(K_{t+1}, X_{t+1})] \quad (\text{B1})$$

where

$$\Psi(K_t, K_{t+1}) \equiv \Phi(K_{t+1} - (1 - \delta)K_t, K_t) \quad (\text{B2})$$

The envelope condition is:

$$V_1(K_t, X_t) = \Pi_1(K_t, X_t) - \Psi_1(K_t, K_{t+1}) \quad (\text{B3})$$

and the first-order condition is:

$$-\Psi_2(K_t, K_{t+1}) + E_t[M_{t+1}V_1(K_{t+1}, X_{t+1})] = 0 \quad (\text{B4})$$

Next, from equation (B2),

$$\begin{aligned} \Psi_1(K_t, K_{t+1})K_t + \Psi_2(K_t, K_{t+1})K_{t+1} &= G' \left(\frac{K_{t+1}}{K_t} - (1 - \delta) \right) K_{t+1}K_t^{\alpha-1} + \alpha G \left(\frac{K_{t+1}}{K_t} - (1 - \delta) \right) K_t^\alpha \\ &+ G' \left(\frac{K_{t+1}}{K_t} - (1 - \delta) \right) K_t^{\alpha-1}K_{t+1} = \alpha\Psi(K_t, K_{t+1}) \end{aligned} \quad (\text{B5})$$

Now plugging equation (B3) into equation (B4) yields the stochastic Euler equation:

$$-\Psi_2(K_t, K_{t+1}) + E_t[M_{t+1}(\Pi_1(K_{t+1}, X_{t+1}) - \Psi_1(K_{t+1}, K_{t+2}))] = 0 \quad (\text{B6})$$

Expanding the value function (B1) recursively and using equations (2) and (B5) to obtain:

$$\begin{aligned} \alpha V(K_t, X_t) &= \Pi_1(K_t, X_t)K_t - \Psi_1(K_t, K_{t+1})K_t - \Psi_2(K_t, K_{t+1})K_{t+1} \\ &+ E_t[M_{t+1}[\Pi_1(K_{t+1}, X_{t+1})K_{t+1} - \Psi_1(K_{t+1}, K_{t+2})K_{t+1} - \Psi_2(K_{t+1}, K_{t+2})K_{t+2} \\ &+ E_{t+1}[M_{t+1,t+2}V(K_{t+2}, X_{t+2})]]] = \dots = \Pi_1(K_t, X_t)K_t - \Psi_1(K_t, K_{t+1})K_t = V_1(K_t, X_t)K_t \end{aligned}$$

where the third equality follows from recursive substitution and from equation (B6). The last equality follows from the envelope condition (B3). ■

Proof of Lemma 2 Solving equation (9) forward yields

$$\begin{aligned} q_t &= E_t[M_{t+1}(\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}))] + E_t[M_{t+1}(1 - \delta)q_{t+1}] \\ &= E_t[M_{t+1}(\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}))] + \\ &E_t[M_{t+1}(1 - \delta)E_{t+1}[M_{t+2}(\Pi_1(K_{t+2}, X_{t+2}) - \Phi_2(I_{t+2}, K_{t+2}) + (1 - \delta)q_{t+2})]] \\ &= E_t[M_{t+1}(\Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1})) + M_{t+2}(1 - \delta)(\Pi_1(K_{t+2}, X_{t+2}) - \Phi_2(I_{t+2}, K_{t+2}))] \\ &+ E_t[M_{t+2}(1 - \delta)^2q_{t+2}] = \dots = E_t\left[\sum_{j=1}^{\infty} M_{t+j}(1 - \delta)^{j-1}(\Pi_1(K_{t+j}, X_{t+j}) - \Phi_2(I_{t+j}, K_{t+j}))\right] \end{aligned}$$

where the last two equalities follow from recursive substitution. ■

Proof of Proposition 1 From Proposition 1, $V_1(K_t, X_t)K_t = \alpha V(K_t, X_t)$. Both sides can be rewritten as: $\Pi_1(K_t, X_t)K_t - \Phi_2(I_t, K_t)K_t + q_t(1 - \delta)K_t = \alpha P_t + \alpha \Pi(K_t, X_t) - \alpha \Phi(I_t, K_t)$. Simplifying using homogeneity of $\Pi(K_t, X_t)$ and $\Phi(I_t, K_t)$ yields $q_t(1 - \delta)K_t = \alpha P_t - \Phi_1(I_t, K_t)I_t$. Equation (12) now follows because $q_t = \Phi_1(I_t, K_t)$ from equation (8). ■

Proof of Lemma 3 The first inequality is shown in the text. Now from Lemma 1 and equations (8) and (13),

$$\Phi_{12}(I_t, K_t) = \frac{\partial q_t}{\partial K_t} = E_t\left[M_{t+1}\frac{\partial V_1(K_{t+1}, X_{t+1})}{K_t}\right] = (1 - \delta)E_t[M_{t+1}V_{11}(K_{t+1}, X_{t+1})] \quad (\text{B7})$$

But differentiating both sides of $\alpha V(K_t, X_t) = V_1(K_t, X_t)K_t$ yields:

$$V_{11}(K_t, X_t) = \frac{(\alpha - 1)}{K_t}V_1(K_t, X_t) = \frac{(\alpha - 1)}{K_t}\alpha\frac{V(K_t, X_t)}{K_t} = \frac{(\alpha - 1)}{K_t}\alpha\widehat{Q}_t \leq 0 \quad (\text{B8})$$

This says that the value function is weakly concave in capital. Now plugging equation (B8) into (B7) yields: $\Phi_{12}(I_t, K_t) = (1 - \delta)(\alpha - 1)\frac{1}{K_{t+1}}E_t[M_{t+1}\alpha\widehat{Q}_{t+1}] = (1 - \delta)(\alpha - 1)\frac{q_t}{K_{t+1}} \leq 0$. Differentiating both sides with respect to K_t yields: $\Phi_{122}(I_t, K_t) = (\alpha - 1)(1 - \delta)\frac{1}{K_{t+1}}\frac{\partial q_t}{\partial K_t} +$

$$(\alpha - 1)(1 - \delta)^2 q_t \left(-\frac{1}{K_{t+1}^2} \right) \geq 0. \quad \blacksquare$$

Proof of Proposition 2 First express stock return in equation (16) in terms of cum-dividend firm value as $r_{t+1}^S = \frac{V(K_{t+1}, X_{t+1})}{V(K_t, X_t) - \Pi(K_t, X_t) + \Psi(K_t, K_{t+1})}$. The recursive value function (B1) evaluated at the optimum then yields $E_t[M_{t+1} r_{t+1}^S] = 1$.

Combining equations (B3) and (B4) yields an alternative investment return, r_{t+1}^I :

$$r_{t+1}^I = \frac{V_1(K_{t+1}, X_{t+1})}{\Psi_2(K_t, K_{t+1})} = \frac{\Pi_1(K_{t+1}, X_{t+1}) - \Psi_1(K_{t+1}, K_{t+2})}{\Psi_2(K_t, K_{t+1})} \quad (\text{B9})$$

which is equal to equation (15) since (B2) implies $\Psi_2 = \Phi_1$ and $\Psi_1 = \Phi_2 - \Phi_1(1 - \delta)$. Now,

$$\begin{aligned} r_{t+1}^I &= \frac{V_1(K_{t+1}, X_{t+1})}{\Psi_2(K_t, K_{t+1})} = \frac{V_1(K_{t+1}, X_{t+1})K_{t+1}}{\alpha\Psi(K_t, K_{t+1}) - \Psi_1(K_t, K_{t+1})K_t} \\ &= \frac{V_1(K_{t+1}, X_{t+1})K_{t+1}}{V_1(K_t, X_t)K_t - \Pi_1(K_t, X_t)K_t + \alpha\Psi(K_t, K_{t+1})} \\ &= \frac{\alpha V(K_{t+1}, X_{t+1})}{\alpha V(K_t, X_t) - \alpha\Pi(K_t, X_t) + \alpha\Psi(K_t, K_{t+1})} = r_{t+1}^S \end{aligned}$$

where the first equality follows from equation (B9), the second follows from equation (B5), the third equality follows from the envelope condition (B3), and the fourth equality follows from Lemma 1 and equation (2). \blacksquare

Lemma 4 Define the numerator of investment return:

$$U_{t+1} \equiv \Pi_1(K_{t+1}, X_{t+1}) - \Phi_2(I_{t+1}, K_{t+1}) + (1 - \delta)\Phi_1(I_{t+1}, K_{t+1}) \quad (\text{B10})$$

Under Assumptions 1-3, $U_{t+1} > 0$, and the (gross) returns are positive, $r_{t+1} = \frac{U_{t+1}}{\Phi_1(I_t, K_t)} > 0$.

Proof. $\Pi_1 > 0$ and $\Phi_2 \leq 0$ follow from Assumptions 1 and 2, respectively. And $\Phi_1 = q_t > 0$ follows from Lemma 3. \blacksquare

Proof of Proposition 3 From equation (2), $\Pi_1(K_t, X_t) = \alpha \left(\frac{\Pi_t}{K_t} \right) = \alpha \left(\frac{N_t}{K_t} + \delta \right)$. Equation (15) then implies that

$$\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{\alpha}{q_t} + \frac{K_{t+1}^{\alpha-1}}{q_t} E_t \left[\left((1 - \alpha)G' \left(\frac{I_{t+1}}{K_{t+1}} \right) + G'' \left(\frac{I_{t+1}}{K_{t+1}} \right) \frac{K_{t+2}}{K_{t+1}} \right) \frac{\partial(I_{t+1}/K_{t+1})}{\partial q_{t+1}} \frac{\partial q_{t+1}}{\partial E_t[N_{t+1}/K_{t+1}]} \right]$$

But equation (8) implies that $\frac{\partial(I_{t+1}/K_{t+1})}{\partial q_{t+1}} = \frac{K_{t+1}^{1-\alpha}}{G''(I_{t+1}/K_{t+1})}$ and equation (10) implies that $\frac{\partial q_{t+1}}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{\rho_\pi}{r_{ft+1}}$. Using these results and noting that $q_t = \alpha Q_t = \alpha \frac{P_t}{K_{t+1}}$ yields:

$$\frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} = \frac{K_{t+1}}{P_t} \left(1 + \frac{1}{\alpha} E_t \left[\left((1 - \alpha) \frac{G'(I_{t+1}/K_{t+1})}{G''(I_{t+1}/K_{t+1})} + \frac{K_{t+2}}{K_{t+1}} \right) \frac{\rho_\pi}{r_{ft+1}} \right] \right)$$

which is positive and decreasing in the market value, P_t . ■

Proof of Proposition 4 Proposition 4 follows directly from the proof of Proposition 3 by noting that $\frac{\partial E_t[r_{t+1}]}{\partial(N_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} \frac{\partial E_t[N_{t+1}/K_{t+1}]}{\partial(N_t/K_t)} = \rho_\pi \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]}$. ■

Proof of Proposition 5 Proposition 5 also follows directly from the proof of Proposition 3 by noting that $\frac{\partial E_t[r_{t+1}]}{\partial \varepsilon_t^\pi} = \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]} \frac{\partial E_t[N_{t+1}/K_{t+1}]}{\partial(N_t/K_t)} \frac{\partial E_t[N_t/K_t]}{\partial \varepsilon_t^\pi} = \rho_\pi \frac{\partial E_t[r_{t+1}]}{\partial E_t[N_{t+1}/K_{t+1}]}$. ■

Proof of Proposition 6 From equations (4) and (15),

$$r_{t+1} = \frac{U_{t+1}}{\Phi_1(I_t, K_t)} = \frac{U_{t+1}}{G'(I_t/K_t)K_t^{\alpha-1}} \quad (\text{B11})$$

$$\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} = -\frac{E_t[U_{t+1}]}{K_t^{\alpha-1}[G'(I_t/K_t)]^2} G''\left(\frac{I_t}{K_t}\right) + \frac{1}{\Phi_1(I_t, K_t)} \frac{\partial E_t[U_{t+1}]}{\partial(I_t/K_t)} \quad (\text{B12})$$

where the first term in equation (B12) is less than zero because Assumption 3 implies $G''(\cdot) > 0$. It then suffices to show that $\frac{\partial E_t[U_{t+1}]}{\partial(I_t/K_t)} < 0$. But plugging equation (3) into (B10) yields:

$$\begin{aligned} E_t[U_{t+1}] &= E_t \left[\Pi_1 \left(\left[\frac{I_t}{K_t} + (1-\delta) \right] K_t, X_{t+1} \right) \right. \\ &\quad - \Phi_2 \left(K_{t+2} - (1-\delta) \left[\frac{I_t}{K_t} + (1-\delta) \right] K_t, \left[\frac{I_t}{K_t} + (1-\delta) \right] K_t \right) \\ &\quad \left. + (1-\delta) \Phi_1 \left(K_{t+2} - (1-\delta) \left[\frac{I_t}{K_t} + (1-\delta) \right] K_t, \left[\frac{I_t}{K_t} + (1-\delta) \right] K_t \right) \right] \quad (\text{B13}) \end{aligned}$$

Differentiating both sides with respect to (I_t/K_t) yields:

$$\begin{aligned} \frac{\partial E_t[U_{t+1}]}{\partial(I_t/K_t)} &= E_t[\Pi_{11}(K_{t+1}, X_{t+1})K_t + 2(1-\delta)\Phi_{12}(I_{t+1}, K_{t+1})K_t - \Phi_{22}(I_{t+1}, K_{t+1})K_t \\ &\quad - (1-\delta)^2\Phi_{11}(I_{t+1}, K_{t+1})K_t] < 0 \quad (\text{B14}) \end{aligned}$$

where the inequality follows from Assumptions 1 and 2 and Lemma 3. Finally, plugging equations (2), (B10), (B14), and (21) into (B12) and using $\Pi_{11}(K_{t+1}, X_{t+1}) = \alpha(\alpha - 1)\frac{\Pi_{t+1}}{K_{t+1}}\frac{1}{K_{t+1}}$:

$$\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right| / \partial \left(\frac{\Pi_t}{K_t} \right) = \frac{\alpha\rho_\pi G''(I_t/K_t)}{\Phi_1(I_t, K_t)G'(I_t/K_t)} + \alpha(1-\alpha)\rho_\pi \frac{K_t}{K_{t+1}} > 0 \quad (\text{B15})$$

■

Proof of Proposition 7 From the investment-return equation (15),

$$\frac{\partial \mathbb{E}_t[r_{t+1}]}{\partial Q_t} = -\frac{\mathbb{E}_t[U_{t+1}]}{\alpha Q_t^2} + \frac{1}{\alpha Q_t} \frac{\partial \mathbb{E}_t[U_{t+1}]}{\partial Q_t} \quad (\text{B16})$$

By Lemma 4, to show $\frac{\partial \mathbb{E}_t[r_{t+1}]}{\partial Q_t} < 0$, it suffices to show that $\frac{\partial \mathbb{E}_t[U_{t+1}]}{\partial Q_t} < 0$. But $I_t/K_t = G'^{-1}(q_t K_t^{1-\alpha})$, from equation (8). Writing q_t further as αQ_t , plugging I_t/K_t into equation (B13), and using the Inverse Function Theorem yield $\partial(I_t/K_t)/\partial Q_t = \alpha K_t^{1-\alpha}/G''(G'^{-1}(\alpha Q_t K_t^{1-\alpha}))$, where $G'^{-1}(\cdot)$ is the inverse function of G' . Now by the chain rule and equation (B14),

$$\begin{aligned} \frac{\partial \mathbb{E}_t[U_{t+1}]}{\partial Q_t} &= \frac{\alpha K_t^{1-\alpha} K_t}{G''(G'^{-1}(\alpha Q_t K_t^{1-\alpha}))} \mathbb{E}_t[\Pi_{11}(K_{t+1}, X_{t+1}) + 2(1-\delta)\Phi_{12}(I_{t+1}, K_{t+1}) \\ &\quad - \Phi_{22}(I_{t+1}, K_{t+1}) - (1-\delta)^2\Phi_{11}(I_{t+1}, K_{t+1})] < 0 \end{aligned} \quad (\text{B17})$$

where the inequality follows because $\Pi_{11} \leq 0$, $\Phi_{12} \leq 0$, $\Phi_{22} \geq 0$, and $\Phi_{11} > 0$.

To establish the second inequality in the proposition, it suffices to show:

$$\frac{\partial^2 \mathbb{E}_t[r_{t+1}]}{\partial Q_t^2} > 0 \quad (\text{B18})$$

because the chain rule of partial derivatives implies that $\partial \left| \frac{\partial \mathbb{E}_t[r_{t+1}]}{\partial Q_t} \right| / \partial P_t = -\frac{\partial^2 \mathbb{E}_t[r_{t+1}]}{\partial Q_t \partial P_t} = -\partial \left(\frac{\partial \mathbb{E}_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial P_t} \right) / \partial Q_t = -\frac{\partial^2 \mathbb{E}_t[r_{t+1}]}{\partial Q_t^2} \frac{\partial Q_t}{\partial P_t} = -\frac{\partial^2 \mathbb{E}_t[r_{t+1}]}{\partial Q_t^2} \frac{1}{K_{t+1}}$. From equation (B16), $\frac{\partial^2 \mathbb{E}_t[r_{t+1}]}{\partial Q_t^2} = \frac{2\mathbb{E}_t[U_{t+1}]}{\alpha Q_t^3} - \frac{2}{\alpha Q_t^2} \frac{\partial \mathbb{E}_t[U_{t+1}]}{\partial Q_t} + \frac{1}{\alpha Q_t} \frac{\partial^2 \mathbb{E}_t[U_{t+1}]}{\partial Q_t^2}$. To show equation (B18), it suffices to show $\frac{\partial^2 \mathbb{E}_t[U_{t+1}]}{\partial Q_t^2} \geq 0$ because $\frac{\partial \mathbb{E}_t[U_{t+1}]}{\partial Q_t} < 0$.

For notational convenience, denote the term in the conditional expectation in equation (B17) as W_{t+1} that is negative. Now substituting $K_{t+1} = [G'^{-1}(\alpha Q_t K_t^{1-\alpha}) + (1-\delta)] K_t$ and $I_{t+1} = K_{t+2} - (1-\delta)[G'^{-1}(\alpha Q_t K_t^{1-\alpha}) + (1-\delta)] K_t$ into equation (B17) and differentiating the equation with respect to Q_t yield:

$$\frac{\partial^2 \mathbb{E}_t[U_{t+1}]}{\partial Q_t^2} = -\alpha^2 K_t^{2(1-\alpha)} K_t \frac{G'''(I_t/K_t)}{[G''(I_t/K_t)]^3} \mathbb{E}_t[W_{t+1}] + \frac{\alpha K_t^{1-\alpha} K_t}{G''(\alpha Q_t K_t^{1-\alpha})} \frac{\partial \mathbb{E}_t[W_{t+1}]}{\partial Q_t} \quad (\text{B19})$$

To show $\frac{\partial^2 \mathbb{E}_t[U_{t+1}]}{\partial Q_t^2} \geq 0$, it suffices to show that $\frac{\partial \mathbb{E}_t[W_{t+1}]}{\partial Q_t} \geq 0$ because the first term in equation (B19) is nonnegative (Lemma 3 and Assumption 5 imply that $W_{t+1} < 0$ and $G'''(\cdot) \geq 0$ because $\Phi_{111} \geq 0$). But, $\frac{\partial \mathbb{E}_t[W_{t+1}]}{\partial Q_t} = \frac{\alpha K_t^{1-\alpha} K_t}{G''(I_t/K_t)} \mathbb{E}_t[\Pi_{111}(K_{t+1}, X_{t+1}) - 3(1-\delta)^2\Phi_{112}(I_{t+1}, K_{t+1}) + 3(1-\delta)\Phi_{122}(I_{t+1}, K_{t+1}) - \Phi_{222}(I_{t+1}, K_{t+1}) + (1-\delta)^3\Phi_{111}(I_{t+1}, K_{t+1})] \geq 0$, where the inequality follows from Assumption 5 and Lemma 3. ■

Proof of Proposition 8 $\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} > 0$ follows from equation (B18). Equation (8) and Proposition 1 imply that $Q_t = G'(I_t/K_t)K_t^{\alpha-1}/\alpha$, which in turn implies that

$$\frac{\partial Q_t}{\partial(I_t/K_t)} = \frac{1}{\alpha} G'' \left(\frac{I_t}{K_t} \right) K_t^{\alpha-1} > 0 \quad (\text{B20})$$

$$\frac{\partial^2 Q_t}{\partial(I_t/K_t)\partial P_t} = \frac{\partial(1/K_{t+1})}{\partial(I_t/K_t)} = -\frac{K_t}{K_{t+1}^2} < 0 \quad (\text{B21})$$

Now, $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right| / \partial P_t = -\partial \left(\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right) / \partial P_t = -\partial \left(\frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial(I_t/K_t)} \right) / \partial P_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} \frac{\partial Q_t}{\partial(I_t/K_t)} - \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial^2 Q_t}{\partial(I_t/K_t)\partial P_t}$. From $\frac{\partial E_t[r_{t+1}]}{\partial Q_t} < 0$ and equations (B20) and (B21), to show the second inequality in the proposition, it suffices to show $\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} > 0$. But,

$$\begin{aligned} \frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} &= \partial \left(\frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial P_t} \right) / \partial Q_t = \frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{1}{K_{t+1}} + \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial^2 Q_t}{\partial Q_t \partial P_t} \\ &= \frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{1}{K_{t+1}} > 0 \end{aligned} \quad (\text{B22})$$

and $\partial \left| \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \right| / \partial Q_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)\partial Q_t} = -\partial \left(\frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial(I_t/K_t)} \right) / \partial Q_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{\partial Q_t}{\partial(I_t/K_t)} + \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial^2 Q_t}{\partial(I_t/K_t)\partial Q_t} = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{\partial Q_t}{\partial(I_t/K_t)} < 0$, where the equality follows because $\frac{\partial^2 Q_t}{\partial(I_t/K_t)\partial Q_t} = \partial \left(\frac{\partial Q_t}{\partial Q_t} \right) / \partial \left(\frac{I_t}{K_t} \right) = 0$.

Finally, taking partial derivative of equation (B12) with respect to $\frac{I_t}{K_t}$ yields: $\frac{\partial^2 E_t[r_{t+1}]}{\partial(I_t/K_t)^2} = \frac{2[G''(I_t/K_t)]^2 - G'''(I_t/K_t)G'(I_t/K_t)}{K_t^{\alpha-1}[G'(I_t/K_t)]^2} E_t[U_{t+1}] - \frac{2G''(I_t/K_t)}{K_t^{\alpha-1}[G'(I_t/K_t)]^2} \frac{\partial E_t[U_{t+1}]}{\partial(I_t/K_t)} + \frac{1}{G'(I_t/K_t)K_t^{\alpha-1}} \frac{\partial^2 E_t[U_{t+1}]}{\partial(I_t/K_t)^2}$. The second term is positive because $\frac{\partial E_t[U_{t+1}]}{\partial(I_t/K_t)} < 0$ from equation (B14), and the third term is nonnegative because $\frac{\partial^2 E_t[U_{t+1}]}{\partial(I_t/K_t)^2} = K_t \frac{\partial E_t[W_{t+1}]}{\partial(I_t/K_t)} = K_t \frac{\partial E_t[W_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial(I_t/K_t)} \geq 0$. And the first term is nonnegative when $2 \left[G'' \left(\frac{I_t}{K_t} \right) \right]^2 \geq G''' \left(\frac{I_t}{K_t} \right) G' \left(\frac{I_t}{K_t} \right)$. ■

Proof of Proposition 9 First, when $\Pi_t - \Phi_t \leq 0$ or $C_t = 0$, the two derivatives in the proposition are exactly zero. Now consider the case when $C_t > 0$; so I can ignore the indicator function. Equation (25) implies that

$$\frac{C_t}{K_t} = \frac{\Pi_t}{K_t} - G \left(\frac{I_t}{K_t} \right) K_t^{\alpha-1} \quad \text{or} \quad \frac{I_t}{K_t} = G^{-1} \left[\left(\frac{\Pi_t}{K_t} - \frac{C_t}{K_t} \right) K_t^{1-\alpha} \right] \quad (\text{B23})$$

where $G^{-1}(\cdot)$ is the inverse function of G , and is also an increasing function because G is around the neighborhood of optimal investment rate.

Now by the chain rule, $\frac{\partial E_t[r_{t+1}]}{\partial(C_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(C_t/K_t)} = -\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{K_t^{1-\alpha}}{G'(I_t/K_t)} > 0$, where the inequality follows because Proposition 6 says that $\frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} < 0$. Next, again by the chain rule, $\frac{\partial^2 E_t[r_{t+1}]}{\partial(C_t/K_t)\partial Q_t} = -\partial \left(\frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial(C_t/K_t)} \right) / \partial Q_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{\partial Q_t}{\partial(C_t/K_t)} + \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial^2 Q_t}{\partial(C_t/K_t)\partial Q_t} =$

$\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t^2} \frac{\partial Q_t}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(C_t/K_t)} < 0$, where the inequality follows from the inequality (B18) and equation (B20). ■

Proof of Proposition 10 When $O_t=0$, the two derivatives in the proposition are exactly zero. Consider the case when $O_t>0$. Now equation (26) implies that

$$\frac{O_t}{K_t} = G\left(\frac{I_t}{K_t}\right) K_t^{\alpha-1} - \frac{\Pi_t}{K_t} \quad \text{or} \quad \frac{I_t}{K_t} = G^{-1}\left[\left(\frac{O_t}{K_t} + \frac{\Pi_t}{K_t}\right) K_t^{1-\alpha}\right] \quad (\text{B24})$$

Now by the chain rule and Proposition 6, $\frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} = \frac{\partial E_t[r_{t+1}]}{\partial(I_t/K_t)} \frac{K_t^{1-\alpha}}{G'(I_t/K_t)} < 0$. And again by the chain rule, $\partial \left[\frac{\partial E_t[r_{t+1}]}{\partial(O_t/K_t)} \right] / \partial P_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial(O_t/K_t)\partial P_t} = -\partial \left(\frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial Q_t}{\partial(O_t/K_t)} \right) / \partial P_t = -\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} \frac{\partial Q_t}{\partial(O_t/K_t)} - \frac{\partial E_t[r_{t+1}]}{\partial Q_t} \frac{\partial^2 Q_t}{\partial(O_t/K_t)\partial P_t}$. To show the left-hand-side is negative, it suffices to show that $\frac{\partial^2 Q_t}{\partial(O_t/K_t)\partial P_t} < 0$ because $\frac{\partial^2 E_t[r_{t+1}]}{\partial Q_t \partial P_t} > 0$ from equation (B22), $\frac{\partial Q_t}{\partial(O_t/K_t)} = \frac{\partial Q_t}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} > 0$, and $\frac{\partial E_t[r_{t+1}]}{\partial Q_t} < 0$. But, $\frac{\partial^2 Q_t}{\partial(O_t/K_t)\partial P_t} = \frac{\partial(1/K_{t+1})}{\partial(I_t/K_t)} \frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} < 0$, where the inequality follows from equation (B21) and $\frac{\partial(I_t/K_t)}{\partial(O_t/K_t)} > 0$. ■