Growth Opportunities, Technology Shocks, and Asset Prices

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ABSTRACT

We explore the impact of investment-specific technology (IST) shocks on the crosssection of stock returns. IST shocks reflect technological advances embodied in new capital goods. Using a structural model, we show that IST shocks have a differential effect on the two fundamental components of firm value, the value of assets in place and the value of growth opportunities. This differential sensitivity to IST shocks has two main implications. First, risk premia on firms with abundant growth opportunities are different from those on firms with limited growth opportunities. Second, firms with similar levels of growth opportunities comove with each other, giving rise to the value factor in stock returns. Our model replicates the failure of the conditional CAPM to capture the value premium. Our empirical tests confirm the model's predictions for asset returns and investment rates.

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Introduction

Technological innovation is a key determinant of economic growth. In many cases, technological innovations affect aggregate output and consumption only to the extent that they are implemented through the formation of new capital stock. Such innovations are termed *investment-specific*, since they are embodied in new capital goods. The magnitude of investment-specific technical progress can be inferred from the decline in the quality-adjusted price of investment goods.[1] The recent literature on real determinants of economic growth has emphasized the role of investment-specific shocks as an important driver of long-run growth and business cycle fluctuations. In this paper, we argue that investment-specific (IST) shocks are helpful in understanding the patterns of risk premia and comovement in the cross-section of firms.

We start with the standard decomposition of firm value into the value of assets in place and the value of growth opportunities. Firms that are relatively rich in growth opportunities have higher demand for new capital goods. As a result, a positive IST shock, manifesting as a reduction in the quality-adjusted price of new capital goods, has a larger positive impact on the market value of such firms. This mechanism produces two important patterns in asset returns. First, firms with a higher ratio of growth opportunities to their market value (high-growth firms) earn different risk premia from firms with fewer growth opportunities (low-growth firms). Second, returns on high-growth firms comove with each other, which creates a systematic factor in stock returns distinct from the market portfolio. Both of these patterns replicate the well-documented properties of value and growth stocks (e.g., Fama and

[1] A classic example of investment-specific technological change is computers. In 2011, a typical computer server costs \$5,000. In 1960, a state of the art computer server (e.g., the Burroughs 205), cost \$5.1 million in 2011 dollars. Furthermore, adjusting for quality is important: a modern computer server would cost \$160.8 million in 1960, using the quality-adjusted NIPA deflator for computers and software. Greenwood (1999) offers numerous additional examples of investment-specific technological change since the industrial revolution: Watt's steam engine, Crompton's spinning mule, and the dynamo. These innovations were embodied in new vintages of capital goods, hence they required substantial new investments before they could affect the production of consumption goods.

French (1993)), because in our model firms' market-to-book ratios are positively correlated with their growth opportunities.

The premise that IST shocks affect assets in place and growth opportunities differently is at the heart of our argument, and distinguishes our theory from other proposed explanations of return comovement and the value premium in stock returns. We test two main implications of this core mechanism. First, a firm's stock return exposure to IST shocks is increasing in the share of growth opportunities in firm value. Second, since firms must invest to realize their growth opportunities, high-growth firms increase investment relatively more following a positive IST shock. Since growth opportunities are not directly observable, we test these implications jointly using the firm's stock return beta on the IST shock as a measure of its growth opportunities. As an alternative strategy, we test both predictions using the market-to-book ratio as an approximate measure of growth opportunities.

Firms' growth opportunities change over time, thus we need to estimate time-varying stock return sensitivities to IST shocks. The macroeconomic literature typically measures IST shocks using the quality-adjusted price of equipment. However, this price series is available only at low frequencies. Our model suggests a natural mimicking portfolio for IST shocks: the difference between stock returns of investment-good producers and consumption-good producers (IMC). The key benefit of this stock-return based measure of IST shocks is that it is available at high frequency. In our tests, we use the IMC portfolio to estimate the conditional stock return betas with respect to the IST shocks. We find that firms with high IST betas tend to have higher Tobin's Q, have higher investment rates in physical capital, hold more cash, pay less in dividends, and invest more in R&D. The tests of the model's mechanism show that, following a positive IST shock, firms with higher IST betas increase their investment relative to firms with low IST betas. The same pattern holds for high and low book-to-market firms. This pattern is both statistically and economically significant. The difference in IST shock sensitivity between the investment of high-growth and low-growth firms is in most cases substantially larger than the sensitivity of investment of an average firm. These results show that cross-sectional differences in IST risk exposures are linked to differences in growth opportunities among firms.

Sorting firms on their IST betas results in a declining profile of average stock returns and an increasing profile of market betas. Hence, the CAPM significantly misprices these portfolios. The difference in average annualized returns and CAPM alphas between the high and low IST-beta decile portfolios is -3.2% and -7.1% respectively. This finding implies that IST shocks are a systematic risk factor that carries a negative risk premium. In addition, we find that firms with higher market-to-book ratios are more exposed to IST shocks. This confirms that heterogeneous exposure to IST shocks generates co-movement among stocks with similar book-to-market ratios.

Our model replicates the dispersion in risk premia and comovement associated with differences in growth opportunities, and the failure of the CAPM to price the cross-section of expected returns. The model generates lower average returns for high IMC-beta and high market-to-book firms, assuming a negative price of risk for IST shocks. We verify that our calibration is consistent with the data by estimating the stochastic discount factor implied by the model using three different cross-sections of assets: portfolios of firms sorted on IMC-beta, book-to-market portfolios, and industry portfolios. We find that a higher exposure to IST shocks is associated with lower risk premia, across the discount factor specifications and test assets. Furthermore, differences in IST shock exposure account for a significant fraction of the heterogenity in risk premia among the test assets.

Our model also replicates the dynamics of cash flows and profitability of value and growth firms documented by Fama and French (1995). In the year of portfolio formation, growth firms have higher average profitability than value firms. In the years following portfolio formation, the average profitability of growth firms declines, whereas the average profitability of value firms rises. Despite the fall in average profitability, the earnings of growth firms grow faster than the earnings of value firms. In the model, this pattern of mean reversion in profitability is driven partly by the fact that growth firms invest relatively more on average. As growth firms accumulate capital, they become similar to value firms.

In summary, our analysis highlights that IST shocks are an important source of systematic risk. IST shocks naturally lead to patterns of stock return comovement among firms with different growth opportunities, and thus give rise to the value factor. Heterogenous exposure to IST shocks is an important source of cross-sectional heterogeneity in risk premia. Our mechanism has a number of implications for stock returns and firm investment behavior, which we confirm empirically. We verify that a parsimonious structural model is able to account for several key empirical patterns quantitatively, providing additional support for our theory.

The rest of the paper is organized as follows. In Section 1 we relate our work to the existing literature. In Section 2 we develop our theoretical model. In Section 3, we discuss the data construction and the calibration of our model. In Section 4 we test its empirical predictions. We conclude in Section 5.

1 Related Research

Our paper bridges and complements two distinct strands of the finance and macroeconomic literature. The first argues for the importance of investment-specific shocks for aggregate growth and fluctuations, and the second argues that differences in a firm's mix between growth opportunities and assets in place are important for understanding the cross-section of expected stock returns.

Investment-specific (IST) shocks capture the idea that technical change is embodied in new equipment. Starting with Solow (1960), a number of economists have proposed embodied technical change as an alternative to the unrealistic disembodied technology shocks in most macroeconomic models.[2] Cummins and Violante (2002) document significant instances of

[2] Solow (1960, p 91) is sceptical of disembodied technology shocks: "...This conflicts with the casual observation that many, if not most, innovations need to be embodied in new kinds of durable equipment

investment-specific technical change in numerous industries. In macroeconomics, a number of studies have shown that IST shocks can account for a large fraction of the variability of output and employment, both in the long run and at business cycle frequencies (e.g., Greenwood, Hercowitz, and Krusell (1997, 2000); Christiano and Fisher (2003); Fisher (2006); Justiniano, Primiceri, and Tambalotti (2010)). Given that IST advances lead to improvements in the real investment opportunity set in the economy, they naturally have a differential impact on growth opportunities of firms and their assets in place. Papanikolaou (2011) demonstrates that in a general equilibrium model, IST shocks are positively correlated with the stochastic discount factor under plausible preference specifications, implying a negative price of risk for IST shocks.

In financial economics, the idea that growth opportunities may have different risk characteristics than assets in place is not new (e.g., Berk, Green, and Naik (1999); Gomes, Kogan, and Zhang (2003); Carlson, Fisher, and Giammarino (2004); Zhang (2005)). In these studies, assets in place and growth opportunities have different exposures to systematic risk, which is summarized by firms' market betas. Our work complements this literature by illustrating how investment-specific shocks affect both the differences in risk premia and return comovement between assets in place and growth opportunities. Most of the existing models focus on the risk premia but not on return comovement, and thus feature a single aggregate shock. In models with a single systematic shock, risk premia of firms are closely aligned with their conditional market betas. As a result, such models have limited ability to account for the empirical failures of the conditional CAPM (e.g. Lewellen and Nagel (2006)). The model of Berk et al. (1999) is one of the few exceptions, it incorporates shocks to both aggregate productivity and discount rates.

Our work is also connected to the literature relating asset prices and firm investment. In this literature, Tobin's Q is commonly used as a stock-market based predictor of investment

before they can be made effective. Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models..."

(e.g., Hayashi (1982); Abel (1985); Abel and Eberly (1994, 1996, 1998); Eberly, Rebelo, and Vincent (2008)). Tobin's Q measures the valuation of capital installed in the firm relative to its replacement cost. Thus, Tobin's Q is commonly considered an observable proxy for growth opportunities. We use an alternative empirical measure of growth opportunities that is a unique implication of our model, that is, the stock return beta with respect to IST shocks. Our tests demonstrate that our measure is incrementally informative when controlling for Tobin's Q and other standard empirical predictors of investment.

A growing branch of asset pricing literature in finance relates Q-based theories of investment to stock return behavior (e.g., Cochrane (1991, 1996); Lyandres, Sun, and Zhang (2008); Liu, Whited, and Zhang (2009); Li, Livdan, and Zhang (2009); Chen, Novy-Marx, and Zhang (2010); Li and Zhang (2010)). This literature focuses on the relation between expected stock returns and firms' investment decisions, which follows from firms' optimizing behavior. Our focus is instead on the mechanism behind the joint determination of investment behavior and risk premia. Thus, our work complements the existing studies and offers a potentially fruitful way of improving our understanding of the links between real investment and stock returns.

2 The Model

In this section we develop a structural model of investment. We show that the value of assets in place and the value of growth opportunities have different sensitivity to IST shocks. As a result, the relative weight of growth opportunities in a firm's value can be identified by measuring the exposure of its stock returns to IST shocks.

There are two sectors in our model: the consumption-good sector, and the investment-good sector. IST shocks manifest as changes in the cost of new capital goods. We focus on heterogeneity in growth opportunities among consumption-good producers.

2.1 Consumption-Good Producers

There is a continuum of measure one of infinitely-lived firms producing a homogeneous consumption good. Firms behave competitively, and there is no explicit entry or exit in this sector. Firms are financed only by equity, hence the firm value is equal to the market value of its equity.

Assets in Place

Each firm owns a finite number of individual projects. Firms create projects over time through investment, and projects expire randomly.[3] Let $\mathcal{F}$ denote the set of firms and $\mathcal{J}_t^f$ the set of projects owned by firm f at time t.

Project j managed by firm f produces a flow of output equal to

$$y_{fjt} = \varepsilon_{ft}\, u_{jt}\, x_t\, K_j^{\alpha}, \tag{1}$$

where K_j is physical capital chosen irreversibly at project j's inception date, u_{jt} is the project-specific component of productivity, ε_{ft} is the firm-specific component of productivity, such as managerial skill of the parent firm, and x_t a disembodied productivity shock affecting the output of all existing projects. We assume decreasing returns to scale at the project level, $\alpha \in (0, 1)$. Projects expire independently at rate δ.

The three components of projects' productivity evolve according to

$$d\varepsilon_{ft} = -\theta_\varepsilon(\varepsilon_{ft} - 1)\, dt + \sigma_\varepsilon \sqrt{\varepsilon_{ft}}\, dB_{ft} \tag{2}$$

$$du_{jt} = -\theta_u(u_{jt} - 1)\, dt + \sigma_u \sqrt{u_{jt}}\, dB_{jt} \tag{3}$$

$$dx_t = \mu_x\, x_t\, dt + \sigma_x x_t\, dB_{xt}, \tag{4}$$

[3]Firms with no current projects can be viewed as firms that temporarily left the sector. Likewise, idle firms that begin operating a new project can be viewed as new entrants. Thus, our model implicitly captures entry and exit by firms.

where dB_{ft}, dB_{jt} and dB_{xt} are independent standard Brownian motions. All idiosyncratic shocks are independent of the aggregate shock: $dB_{ft} \cdot dB_{xt} = 0$ and $dB_{jt} \cdot dB_{xt} = 0$. The firm and project-specific components of productivity are stationary processes, while the process for aggregate productivity follows a Geometric Brownian motion, generating long-run growth.

Investment

Firms acquire new projects exogenously according to a Poisson process with a firm-specific arrival rate λ_{ft}. At the time of investment, the project-specific component of productivity is at its long-run average value, $u_{jt} = 1$.

The firm-specific arrival rate of new projects is

$$\lambda_{ft} = \lambda_f \cdot \tilde{\lambda}_{ft} \tag{5}$$

where $\tilde{\lambda}_{ft}$ follows a two-state, continuous-time Markov process with transition probability matrix between time t and $t + dt$ given by

$$P = \begin{pmatrix} 1 - \mu_L \, dt & \mu_L \, dt \\ \mu_H \, dt & 1 - \mu_H \, dt \end{pmatrix}. \tag{6}$$

We label the two states as $[\lambda_H, \lambda_L]$, with $\lambda_H > \lambda_L$. Thus, at any point in time, a firm can be either in the high-growth $(\lambda_f \cdot \lambda_H)$ or in the low-growth state $(\lambda_f \cdot \lambda_L)$, and $\mu_H \, dt$ and $\mu_L \, dt$ denote the instantaneous probability of entering each state respectively. Without loss of generality, we impose that $E[\tilde{\lambda}_{ft}] = 1$, which translates to the restriction

$$1 = \lambda_L + \frac{\mu_H}{\mu_H + \mu_L}(\lambda_H - \lambda_L). \tag{7}$$

When presented with a new project at time t, a firm must make a take-it-or-leave-it decision. If the firm decides to invest in a project, it chooses the associated amount of capital K_j and pays the investment cost $z_t^{-1} x_t K_j$. The cost of capital relative to its average productivity depends on the stochastic process z_t, which follows a Geometric Brownian motion

$$dz_t = \mu_z z_t \, dt + \sigma_z z_t \, dB_{zt}, \tag{8}$$

where $dB_{zt} \cdot dB_{xt} = 0$. The z shock is the embodied, investment-specific (IST) shock in our model, representing the component of the price of capital that is unrelated to its current level of average productivity x. A positive realization of z reduces the cost of new capital goods and thus leads to an improvement in investment opportunities.

Valuation

Let π_t denote the stochastic discount factor. For simplicity, we assume that the aggregate productivity shocks x_t and z_t have constant prices of risk, γ_x and γ_z respectively, and the risk-free interest rate r is also constant. Then,

$$\frac{d\pi_t}{\pi_t} = -r \, dt - \gamma_x \, dB_{xt} - \gamma_z \, dB_{zt}. \tag{9}$$

This form of the stochastic discount factor is motivated by a general equilibrium model with IST shocks in Papanikolaou (2011). IST shocks endogenously affect the representative household's consumption stream, and hence they are priced in equilibrium.

Firms' investment decisions are based on a tradeoff between the market value of a new project and the cost of physical capital. Given (9), the time-t market value of an existing project j, $p(\varepsilon_{ft}, u_{jt}, x_t, K_j)$, is equal to the present value of its cashflows

$$p(\varepsilon_{ft}, u_{jt}, x_t, K_j) = \mathrm{E}_t \left[\int_t^\infty e^{-\delta(s-t)} \frac{\pi_s}{\pi_t} \varepsilon_{fs} u_{js} x_s K_j^\alpha \, ds \right] = A(\varepsilon_{ft}, u_{jt}) x_t K_j^\alpha, \tag{10}$$

where

$$\begin{aligned} A(\varepsilon, u) = & \frac{1}{r + \delta - \mu_X} + \frac{1}{r + \delta - \mu_X + \theta_\varepsilon}(\varepsilon - 1) + \frac{1}{r + \delta - \mu_X + \theta_u}(u - 1) \\ & + \frac{1}{r + \delta - \mu_X + \theta_\varepsilon + \theta_u}(\varepsilon - 1)(u - 1). \end{aligned} \tag{11}$$

Firms' investment decisions are straightforward because the arrival rate of new projects is exogenous and does not depend on their previous decisions. Thus, optimal investment decisions are based on the NPV rule. Firm f chooses the amount of capital K_j to invest in project j to maximize

$$p(\varepsilon_{ft}, 1, x_t, K_j) - z_t^{-1} x_t K_j \tag{12}$$

Proposition 1 *The optimal investment K_j in project j undertaken by firm f at time t is*

$$K^*(\varepsilon_{ft}, z_t) = (\alpha z_t A(\varepsilon_{ft}, 1))^{\frac{1}{1-\alpha}}. \tag{13}$$

The scale of the firm's investment depends on firm-specific productivity, ε_{ft}, and the IST shock z_t. Because the marginal productivity of capital in (1) is infinite at zero, it is always optimal to invest a positive and finite amount.

The value of the firm can be computed as the sum of market values of its existing projects and the present value of its growth opportunities. The former equals the present value of cash flows generated by existing projects. The latter equals the expected discounted NPV of future investments. Following the standard convention, we call the first component of firm value *the value of assets in place*, VAP_{ft}, and the second component *the present value of growth opportunities*, $PVGO_{ft}$.

The value of a firm's assets in place is the value of its existing projects:

$$VAP_{ft} = \sum_{j \in \mathcal{J}_t^f} p(\varepsilon_{ft}, u_{jt}, x_t, K_j) = x_t \sum_{j \in \mathcal{J}_t^f} A(\varepsilon_{ft}, u_{j,t}) K_j^\alpha. \tag{14}$$

The present value of growth opportunities is the net present value of all future projects, which is given by the following proposition.

Proposition 2 *The value of growth opportunities for firm f is*

$$PVGO_{ft} = z_t^{\frac{\alpha}{1-\alpha}} x_t G(\varepsilon_{ft}, \lambda_{ft}), \tag{15}$$

where

$$G(\varepsilon_{ft}, \lambda_{ft}) = C \cdot E_t \left[\int_t^\infty e^{-\rho(s-t)}\, \lambda_{fs}\, A(\varepsilon_{fs})^{\frac{1}{1-\alpha}}\, ds \right]$$
$$= \begin{cases} \lambda_f \left(G_1(\varepsilon_{ft}) + \frac{\mu_L}{\mu_L+\mu_H} (\lambda_H - \lambda_L)\, G_2(\varepsilon_{ft}) \right), & \tilde{\lambda}_{ft} = \lambda_H \\ \lambda_f \left(G_1(\varepsilon_{ft}) - \frac{\mu_H}{\mu_L+\mu_H} (\lambda_H - \lambda_L)\, G_2(\varepsilon_{ft}) \right), & \tilde{\lambda}_{ft} = \lambda_L, \end{cases} \tag{16}$$

and

$$\rho = r - \frac{\alpha}{1-\alpha}(\mu_z + \sigma_z^2/2) - \mu_x - \frac{\alpha^2 \sigma_z^2}{2(1-\alpha)^2}, \tag{17}$$

and

$$C = \alpha^{\frac{1}{1-\alpha}} \left(\alpha^{-1} - 1 \right). \tag{18}$$

The functions $G_1(\varepsilon)$ and $G_2(\varepsilon)$ solve the following differential equations

$$C \cdot A(\varepsilon, 1)^{\frac{1}{1-\alpha}} - \rho\, G_1(\varepsilon) - \theta_\varepsilon(\varepsilon - 1) \frac{d}{d\,\varepsilon}\, G_1(\varepsilon) + \frac{1}{2} \sigma_\varepsilon^2\, \varepsilon\, \frac{d^2}{d\,\varepsilon^2}\, G_1(\varepsilon) = 0, \tag{19}$$
$$C \cdot A(\varepsilon, 1)^{\frac{1}{1-\alpha}} - (\rho + \mu_H + \mu_L)\, G_2(\varepsilon) - \theta_\varepsilon(\varepsilon - 1) \frac{d}{d\,\varepsilon}\, G_2(\varepsilon) + \frac{1}{2} \sigma_e^2\, \varepsilon\, \frac{d^2}{d\,\varepsilon^2}\, G_2(\varepsilon) = 0. \tag{20}$$

Examining equation (15), the value of growth opportunities depends on two systematic sources of risk. In addition to aggregate productivity x, the present value of growth opportunities depends on the IST shock, z, because the net present value of future projects depends on the cost of new investment.

Putting the two pieces together, the total value of the firm is equal to

$$V_{ft} = x_t \sum_j A(\varepsilon_{ft}, u_{jt}) K_j^\alpha + z_t^{\frac{\alpha}{1-\alpha}}\, x_t\, G(\varepsilon_{ft}, \lambda_{ft}). \tag{21}$$

Risk and Risk Premia

Both assets in place and growth opportunities have constant exposure to the systematic shocks dB_{xt} and dB_{zt}. However, their betas with respect to the IST shock z are different. In particular, the value of assets in place is independent of the IST shock z and loads only on the aggregate productivity shock x. In contrast, the present value of growth option depends positively on aggregate productivity x and the IST shock z. Thus, the firm's stock return beta with respect to the IST shock is time-varying, and depends linearly on the fraction of firm value accounted for by growth opportunities:

$$\beta^z_{ft} = \frac{\partial \ln V_{ft}}{\partial \ln z_t} = \frac{\alpha}{1-\alpha}\frac{PVGO_{ft}}{V_{ft}} \tag{22}$$

Since, by assumption, the price of risk of aggregate shocks is constant, the expected excess return of a firm is an affine function of the weight of growth opportunities in firm value, as shown in the following proposition:

Proposition 3 *The expected excess return on firm f is*

$$ER_{ft} - r_f = \gamma_x \sigma_x + \frac{\alpha}{1-\alpha}\gamma_z \sigma_z \frac{PVGO_{ft}}{V_{ft}}. \tag{23}$$

Many existing models of the cross-section of stock returns generate an affine relation between expected stock returns and firms' asset composition similar to (23) (e.g., Berk et al. (1999), Gomes et al. (2003)). The distinguishing feature of our model is the presence of two aggregate shocks x and z. Thus, realized returns have a conditional two-factor structure, and as a result the conditional CAPM fails to price the cross-section of stock returns.

Whether the relation (23) gives rise to a value (or growth) premium depends on the risk premia attached to the two aggregate shocks, γ_x and γ_z. Most equilibrium models imply a positive price of risk for disembodied technology shocks, so $\gamma_x > 0$. The price of risk of the IST shock γ_z depends on preferences. Papanikolaou (2011) shows that under plausible preference parameters, states with low cost of new capital (high z) are high marginal valuation states, which is analogous to a negative value of γ_z. In Papanikolaou (2011), households attach higher marginal valuations to states with a positive IST shock because in those states households substitute resources away from consumption and into investment.

We infer the price of risk of IST shocks from the cross-section of stock returns. In particular, firms' market-to-book (M/B) ratios are positively correlated with the share of growth opportunities to firm value $PVGO_f/V_f$. Empirically, growth firms have relatively high exposure to IST shocks and relatively low expected excess returns. This suggests that the market price of IST shocks is negative.

2.2 Investment-Good Producers

There is a continuum of firms producing new capital goods. We assume that these firms produce the demanded quantity of capital goods at the current unit price z_t. Furthermore, profits of investment firms are a fraction ϕ of total sales of new capital goods.[4] Consequently, profits accrue to investment firms at a rate of $\Pi_t = \phi\, z_t\, x_t\, \overline{\lambda} \int_{\mathcal{F}} K_{ft} df$, where $\overline{\lambda} = \int_{\mathcal{F}} \lambda_{ft}$ is the average arrival rate of new projects among consumption-good producers.[5]

Proposition 4 *The price of the investment firm satisfies*

$$V_{It} = \Gamma\, x_t\, z_t^{\frac{\alpha}{1-\alpha}}, \tag{24}$$

where the constant Γ *equals*

$$\Gamma \equiv \phi\, \overline{\lambda}\, \alpha^{\frac{1}{1-\alpha}}\, \rho^{-1} \left(\int_{\mathcal{F}} A(e_f, 1)^{\frac{1}{1-\alpha}} df \right). \tag{25}$$

The value of the investment firms equals the present value of their cash flows. If we assume that these firms incur proportional costs of producing their output, and given that the market price of risk is constant for the two shocks, the value of the investment firms is proportional to the aggregate investment expenditures in the economy. The stock returns of the investment firms then load on the IST shock z as well as the disembodied productivity shock x.

[4] These assumptions are made for simplicity. Alternatively, we could specify z as the productivity shock to the investment sector, which produces capital goods using a fixed factor of production. The two formulations are equivalent.

[5] The firm-level arrival rate λ_{ft} has a stationary distribution, so $\overline{\lambda}$ is a constant.

A positive IST shock z benefits the investment-good producers. Even though the price of their output declines, the elasticity of investment demand with respect to price is greater than one, so their profits increase. Hence, we can use the relative stock returns of the investment and consumption good producers to create a factor-mimicking portfolio for the IST shock.

We define the IMC portfolio in the model as the portfolio that is long the investment sector and short the consumption sector. The instantaneous return on the IMC portfolio $R_t^I - R_t^C$ is given by

$$R_t^I - R_t^C = E_t[R_t^I - R_t^C]\, dt + \frac{\alpha}{1-\alpha}\, \beta_{0t}\, dB_{zt}, \tag{26}$$

where $\beta_{0t} \equiv \left(\int_{\mathcal{F}} V_{ft}\, df\right)/\left(\int_{\mathcal{F}} VAP_{ft}\, df\right)$ is a term that depends on the fraction of aggregate value that is due to growth opportunities, which affects the IMC portfolio's beta with respect to the z-shock. The beta of firm f with respect to the IMC portfolio return is given by

$$\beta_{ft}^{imc} \equiv \frac{cov_t(R_{ft}, R_t^I - R_t^C)}{var_t(R_t^I - R_t^C)} = \beta_{0t} \left(\frac{PVGO_{ft}}{V_{ft}} \right). \tag{27}$$

Equation (27) is the basis of our empirical approach to measuring growth opportunities. The beta of firm f's return with respect to the IMC portfolio return is proportional to its beta with the investment shock defined in equation (22), and is thus proportional to the fraction of firm f's value represented by its growth opportunities. Firms that have few active projects but expect to create many projects in the future derive most of their value from their future growth opportunities. These firms are anticipated to increase their investment in the future, and their stock price reflects that.

3 Data and Calibration

Here, we describe the construction of our main variables and the calibration of our model.

3.1 Data

We focus our analysis on firms in the consumption-good sector, following our theoretical analysis above. We relegate the details to Appendix A.

Investment-specific shocks

We focus on four measures of capital-embodied technical change directly implied by the model. The first measure of IST shocks is based on the quality-adjusted price of new capital goods, as in Greenwood et al. (1997, 2000). Similar to real business cycle models with IST shocks, in our model the cost of capital goods relative to their productivity z^{-1} is directly related to the IST shock.

We use the quality-adjusted price series of new equipment constructed by Gordon (1990), and extended by Cummins and Violante (2002) and Israelsen (2010). We normalize the price of new equipment by the NIPA consumption deflator. As Fisher (2006) points out, the real equipment price experiences an abrupt increase in its average rate of decline in 1982, which could be due to the effect of more accurate quality adjustment in more recent data (see e.g., Moulton (2001)). To address this issue, we remove the time trend from the series of equipment prices and define investment-specific technological changes as negative of the change in the de-trended log relative price of new equipment goods. Specifically, we construct a de-trended equipment price series z_t^I by regressing the logarithm of the quality-adjusted price of new equipment p^I relative to the NIPA personal consumption deflator on a piece-wise linear time trend:

$$p_t^I = a_0 + b_0 \mathbf{1}_{1982} + (a_1 + b_1 \mathbf{1}_{1982}) \cdot t - z_t^I \tag{28}$$

where $\mathbf{1}_{1982}$ is an indicator function that takes the value 1 post 1982. We measure investment-specific technology shocks as Δz_t^I. Our results are similar when we use residuals from an AR(1) model or simple first differences of the relative price series. The series Δz_t^I is positively correlated with the series of returns on the IMC portfolio. The historical correlation between the two series is 22.3% with a HAC-t-statistic of 2.31.

Our second measure is based on the stock return spread between investment- and consumption-good producers (IMC portfolio). As we see from equation (26), the IMC portfolio is spanned by the IST shock. Hence, we use returns to the IMC portfolio as a factor-mimicking portfolio for IST shocks. To construct the IMC portfolio, we first classify industries as producing either investment or consumption goods according to the NIPA Input-Output Tables. We then match firms to industries according to their NAICS codes. Gomes, Kogan, and Yogo (2009) and Papanikolaou (2011) describe the details of this classification procedure.

As a robustness test, we also consider an additional proxy for IST shocks based on real variables, that is, the ratio of aggregate investment to consumption. In our model, a positive IST shock leads to an improvement in investment opportunities, and therefore to an increase in aggregate investment relative to the output of the consumption sector. As a result, the aggregate log investment-to-consumption ratio is positively correlated with the IST shock z:

$$\ln\left(\frac{I_t}{C_t}\right) = \chi_t + \frac{\alpha}{1-\alpha}\ln z_t, \tag{29}$$

$$\text{where} \quad \chi_t \equiv \ln\left(\overline{\lambda}\,\alpha^{\frac{1}{1-\alpha}}\,\rho^{-1}\int A(\varepsilon_{ft},1)^{\frac{1}{1-\alpha}}df \Big/ \int_{\mathcal{F}}\varepsilon_{ft}\left(\sum_{j\in\mathcal{J}_t^f}u_{jt}K_j^{\alpha}\right)df\right) = a_0 + a_1\ln\left(\int_{\mathcal{J}_t}K_j^{\alpha}\,dj\right), \tag{30}$$

where a_0 and a_1 are constants, and $\mathcal{J}_t$ denotes the set of all existing projects at time t.

Since χ_t is a locally deterministic process, innovations in the investment-to-consumption ratio are driven by the IST shock z. Hence, we construct our alternative proxy for the IST shock z as the first difference of the log ratio of non-residential private investment to consumption of non-durables plus services. Using residuals from an AR(1) model rather than first differences leads to similar results. The correlation between the two real proxies for the investment shock z^I and $\Delta\ln\left(\frac{I_t}{C_t}\right)$ is equal to 34%.

To illustrate the connection in our model between the value factor and IST shocks, we construct the equivalent of the HML portfolio as in Fama and French (1993). To be consistent with our model, we focus on firms producing consumption goods.[6] Our HML portfolio with consumption-sector firms has a correlation of 92% with the Fama and French (1993) HML factor.

In the left panel of Table 1 we show the moments of the two portfolios, IMC and HML constructed using consumption firms only. The IMC portfolio has a negative average return of -1.9% and a standard deviation of 11%, while our version of the value factor has an average return of 3.4% and a standard deviation of 9.3%. In our model, the value factor is negatively correlated with the IST shock z, because firms' market-to-book ratios are positively correlated with the ratio of growth opportunities to firm value. In the data, the correlation between IMC and HML is -56%.

The IMC and HML portfolios are both mispriced by the CAPM, having alphas of -2.9% and 4.1% respectively. Importantly, even though both portfolios are diversified, they have low correlation with the market portfolio (R^2 of 6.7% to 9.9%). Hence, these two portfolios are correlated with a source of systematic risk distinct from the market portfolio. Investment firms tend to be on average smaller than consumption firms, thus the IMC portfolio has a positive size tilt. Its alpha with the market portfolio and the size (SMB) factor is -3.7%. Finally, and consistent with our model, the Fama and French (1993) model prices both portfolios.

Growth opportunities

Here, we construct measures of growth opportunities that are motivated by our model. The firm's asset composition between growth opportunities and assets in place changes over time,

[6] We construct a 2×3 sort, sorting firms first on their market value of equity (CRSP December market capitalization) and then on their ratio of Book-to-Market (Compustat item ceq). We construct the breakpoints using NYSE firms only. We construct our value factor in the consumption sector as $1/2(SV - SG) + 1/2(LV - LG)$, where SG, SV, LG and LV refer to the corner portfolios.

as new projects are acquired, old projects expire, or investment opportunities change. Thus, it is important that our empirical proxies for growth opportunities capture these fluctuations.

Our first empirical measure of growth opportunities is directly implied by our model. Equation (22) shows that the firm's ratio of the value of growth opportunities to total firm value is proportional to the sensitivity of its stock return to the IST shock z. Thus, given our high-frequency proxy for the IST shock (IMC portfolio), we estimate time-varying IST-betas for each firm,

$$r_{ftw} = \alpha_{ft} + \beta_{ft}^{imc} r_{tw}^{imc} + \varepsilon_{ftw}, \qquad w = 1 \ldots 52. \tag{31}$$

Here r_{ftw} refers to the log return of firm f in week w of year t, and r_{ftw}^{imc} refers to the log return of the IMC portfolio in week w of year t. Thus, β_{ft}^{imc} is constructed using information only in year t. The slope estimate of equation (31) is the direct counterpart of equation (27) in the model. To evaluate the accuracy of a firm's estimated IMC-beta as a measure of growth opportunities, we also use equation (31) to estimate β^{imc} in simulated data.

Our second measure of growth opportunities is the firm's market-to-book ratio. The value of growth opportunities enters the market value of the firm but not the book value of capital. Hence, a firm's market-to-book ratio is positively correlated with the ratio of growth opportunities to firm value in our model. We construct the firm's market-to-book ratio as the ratio of the market value equity to the book value of equity.[7]

Both of these measures of growth opportunities are noisy measures of $PVGO/V$. The firm's IMC beta contains estimation noise. The firm's market to book ratio is a noisy measure of growth opportunities because it is influenced by the productivity u of existing projects.[8] Hence, in our empirical analysis we report results using both measures.

[7]In our model firms are financed entirely by equity. Hence, the ratio of market-to-book equity and Tobin's Q are the same. In our empirical work, we use the ratio of market-to-book equity to sort firms into portfolios in order to be close to the literature on the value premium. However, using Tobin's Q instead produces very similar results.

[8]The firm's market-to-book ratio is $\frac{V}{K} = \frac{1}{1-\frac{PVGO}{V}} \times \frac{VAP}{K}$, where K is the value of installed capital $K_{ft} = z_t^{-1} x_t \int_{\mathcal{J}_{ft}} k_j$. Firms with more profitable existing projects have higher ratios VAP/K, and hence higher market-to-book ratios.

3.2 Calibration

We calibrate our model to approximately match moments of aggregate dividend growth and investment growth, accounting ratios, and asset returns. Thus, most of the parameters are chosen jointly based on the behavior of financial and real variables. Table 2 summarizes our parameter choices.

[Table 2]

We model the distribution of mean project arrival rates $\lambda_f = E[\lambda_{ft}]$ across firms as

$$\lambda_f = \mu_\lambda \delta - \sigma_\lambda \delta \log(X_f), \quad X_f \sim U[0,1]. \tag{32}$$

We choose the project decreasing returns-to-scale parameter $\alpha = 0.85$, the parameters governing the projects' cash flows ($\sigma_\varepsilon = 0.2$; $\theta_\varepsilon = 0.35$; $\sigma_u = 1.5$; and $\theta_u = 0.5$), and the parameters of the distribution of λ_f ($\sigma_\lambda = 2$; $\mu_\lambda = 2$), in order to match the average values and the cross-sectional distribution of the investment rate, the market-to-book ratio, and the return to capital.

We select the dynamics of the stochastic component of the firm-specific arrival rate ($\mu_H = 0.075$; $\mu_L = 0.16$; and $\lambda_H = 2.35$) to ensure that the firm grows at about twice the average rate in its high-growth phase and at about a third of the average rate in the low-growth phase.

We set the project expiration rate δ to 10%, to be consistent with commonly used values for the depreciation rate. We choose the parameters governing the dynamics of the shocks x_t and z_t to match the first two moments of the aggregate dividend growth and investment growth. We choose $\phi = 0.07$ to match the relative size of the consumption and investment sectors in the data.

The parameters of the pricing kernel, $\gamma_x = 0.69$ and $\gamma_z = -0.35$ are picked to match approximately the average excess returns on the market portfolio and the IMC portfolio. We set the interest rate r to 2.5%, which is close to the historical average real risk-free rate.

We simulate the model at a weekly frequency ($dt = 1/52$) and time-aggregate the data to form annual observations. We simulate 1,000 samples of 2,500 firms over a period of 100 years. We drop the first half of each simulated sample to eliminate the dependence on initial values. Unless noted otherwise, we report median moments estimates and t-statistics across simulations.

[Table 3]

In Table 3, we compare the estimated moment in the data to the median moment estimate and the 5th and 95th percentiles in simulated data. In most cases, the median moment estimate of the model is close to the empirical estimate. The model matches the moments of aggregate dividend and investment growth, the moments of the market portfolio and the mean and dispersion in most firm characteristics.

In some cases, the model generates median point estimates that are different than the empirical estimates. However, the empirical estimates lie within the 90% confidence intervals implied by the model. First, the model produces a somewhat lower average return on the IMC portfolio, −3.9% vs −1.9% in the data.[9] Second, the distribution of firm size produced by the model is somewhat less skewed than in the data. The ratio of median to average firm size is higher than in the data (0.70 versus 0.20), since the model does not generate a sufficient number of large firms. Similarly, the dispersion of estimated IMC-beta is higher in the data (0.99) than in the model, but this is may be partly due to higher measurement error in the data than in the model. Third, the median value of Tobin's Q in the data is a bit smaller than in the model (1.41 vs 1.98). The average level of Tobin's Q in the model depends on a number of simplifying assumptions, such as the absence of labor costs and financial leverage.

[9] Investment firms tend to be quite a bit smaller than consumption firms, so the size effect may bias the estimated return of the IMC portfolio upwards. Two pieces of evidence support this conjecture: when excluding the month of January, which is when the size effect is strongest, the average return on the IMC portfolio is −3.5%; in addition, its alpha with respect to the Small-minus-Big (SMB) portfolio of Fama and French (1993) is −3.7%, as we see in Table 1.

4 Empirical Implications

In this section, we explore the empirical predictions of our model.

4.1 Inspecting the Mechanism

Here, we explore direct tests of the mechanism. In particular, there are two main predictions of our model. First, growth opportunities are proportional to firms' stock return betas with the IMC portfolio. Second, firms with more growth opportunities increase their investment more following a positive IST shock. Since growth opportunities are not observable directly, we take two approaches. In the first approach, we test both predictions jointly using firms' IMC betas as a measure of growth opportunities. In the second approach, we use the firms' market to book ratios as an approximate measure of growth opportunities. In both cases, we compare our empirical findings to the output of the calibrated model.

Growth opportunities and IMC-beta

Here, we show that our measure of growth opportunities (IMC-beta) is related to firm characteristics commonly associated with growth opportunities. In Table 4, we report the time-series average of firm characteristics in each of the 10 portfolios sorted on IMC-beta. The top panel shows results in the historical data, and the bottom panel shows results in simulated data from the model. As we see in the top panel of Table 4, our portfolio sorting procedure is successful in generating ex-post dispersion in sensitivities with both the IST-mimicking portfolio (IMC, second row) and the IST shock constructed using the price of equipment Δz^I (third row). The difference in sensitivities between the highest and lowest portfolio is statistically significant at the 1% level.

The pattern of firm characteristics across the portfolio deciles is consistent with our interpretation of IMC-beta as measuring heterogeneity in growth opportunities. Within the consumption sector, firms in the highest IMC-beta portfolio invest more (14.8% investment rate) than firms in the lowest IMC-beta portfolio (10.7%). Moreover, highest IMC-beta firms tend to have higher Tobin's Q (2.39), and have higher R&D expenditures (6.0% as a fraction of sales) than lowest IMC-beta firms (1.49 and 1.4% respectively). In addition, high IMC-beta firms seem to exhibit higher preference for liquidity, since they hold more cash (11.4% vs 6.6%) and pay lower dividends (2.8% vs 9.0%) than lowest IMC-beta firms.

High IMC-beta firms tend to be smaller, both in terms of their market capitalization as well as their book value of capital. The highest IMC-beta portfolio accounts for a fraction of 3.9% (2.8%) of the total market capitalization (book value) of capital versus 8.8% (9.8%) for the lowest IMC-beta portfolio. Finally, there is little difference in the ratio of debt to assets across these portfolios, suggesting that these differences in beta are not due to differences in financial leverage.

[Table 4]

As we see in the bottom panel of Table 4, the model mimics most of the empirical patterns above. Firms in the highest IMC-beta portfolio have higher investment rates (14.0%) and higher Tobin's Q (3.30) relative to the firms in the lowest IMC-beta portfolio (7% and 1.05 respectively). In addition, as in the data, high IMC-beta firms tend to have smaller size, measured either by their market capitalization or by their capital stock.

Investment

The main mechanism of our model is that firms with higher growth opportunities, being better positioned to take advantage of positive IST shocks, should increase their investment more in response to a positive IST shock than firms with lower growth opportunities. Since growth opportunities are not observable directly, our empirical tests rely on the observable proxies for growth opportunities motivated by the model. Thus, we jointly evaluate the validity of the main mechanism of our model and the model-based empirical proxies for the IST shocks and the market value of firms' growth opportunities.

We compare the investment response of firms with different measures of growth opportunities (IMC-beta or market-to-book) to a positive IST shock. We use the following specification:

$$i_{ft} = a_1 + \sum_{d=2}^{5} a_d\, D(G_{f,t-1})_d + b_1\, \Delta z_{t-1} + \sum_{d=2}^{5} b_d\, D(G_{f,t-1})_d \Delta z_{t-1} + c\, X_{f,t-1} + u_t, \qquad (33)$$

where i_t is the firm's investment rate; Δz_t refers to measures of the IST shock; $D(G_f)_d$ is a dummy variable that takes the value one if the firm's growth opportunity measure $G_f \in \{\beta_f^{imc}, M_f/B_f\}$ belongs to the quintile d in year $t-1$; X is a vector of controls which includes the firm's Tobin's Q, leverage, cash flows, log of its capital stock relative to the aggregate capital stock, and firm fixed effects. Definitions of these variables are standard and are summarized in Appendix A. We standardize all variables to zero mean and unit standard deviation. We cluster standard errors by firm and year, following Petersen (2009). To evaluate the ability of the model to quantitatively replicate the data, we also estimate (33) using simulated data from the model.

We estimate equation (33) using four proxies for the IST shock implied by the model: i) returns to the IMC portfolio, R^{imc}; ii) our measure based on the price of equipment, Δz^I; iii) the first difference of the aggregate log investment-to-consumption ratio, Δic; and iv) minus the returns to the value factor (using consumption firms only), $-R^{hml}$. To account for time-to-build, we use two lags of each measure as regressors in (33), so for instance $\Delta z_t = R_t^{imc} + R_{t-1}^{imc}$.

We focus on the coefficients $(b_1, \ldots, b_5)$ on the dummy variables, which measure differences in the response of investment to IST shocks. We report the results in Tables 5 and 6. Panel A of Table 5 compares the response of investment to IMC portfolio returns for firms with different measures of growth opportunities. The first column shows that a one-standard-deviation IMC return shock is associated with an increase in firm-level investment by 0.09 standard deviations on average. Columns two and three show how this investment response varies with the firm's IMC-beta. Specifically, the sensitivity of the investment rate to our measure of IST shocks varies between 0.048 for the low-β^{imc} firms and 0.179 for the high-β^{imc} firms. When we include firm-level controls, the difference in investment sensitivity drops somewhat to 0.08, but is still statistically significant at the 1% level. Columns (4) and (5) show that results are similar if we proxy for growth opportunities using market to book ratios.

Our results are similar using the other three measures of IST shocks, as we show in Table 6. Panel A shows that a positive one-standard deviation IST shock constructed using the price of equipment Δz^I is associated with a 0.031 standard deviation increase in investment for the average firm. However, this response varies dramatically in the cross-section, ranging from -0.01 to 0.093 between firms in the low- and high IMC-beta quintiles respectively. Panel B shows that using the investment-to-consumption ratio Δic to measure IST shocks leads to comparable results. Following a positive one-standard deviation shock, high IMC-beta firms increase investment by 0.17 standard deviations, while low IMC-beta firms increase investment by 0.04 standard deviations. Using the market-to-book ratio as a measure of growth opportunities leads to comparable, but often quantitatively smaller effects.

Panel C shows that the common factor in firms' investment rates is related to the value factor in returns. Following a one-standard deviation negative change in the value factor, firms with high IMC-beta (market-to-book) increase investment by 0.071 (0.086) standard deviations, while firms with low IMC-beta (market-to-book) exhibit no statistically significant response.

The magnitude of this investment comovement is economically significant. Our point estimates imply that a positive one-standard deviation shock to Δz_t increases the level of investment rate of high-growth firms relative to low-growth firms by 0.4% to 3.1%, depending on the specification. Fluctuations in the investment rate of this magnitude are substantial relative to the median level of the investment rate (11%) in the population of firms. Moreover, these fluctuations are not diversified across firms. Hence, these fluctuations are also large relative to the unconditional volatility of the aggregate investment rate changes in our sample, which is 2.4%.

Panel B of Table 5 shows that our model generates comovement in investment rates across firms that is quantitatively similar to the data. To conserve space, we only report results using returns to the IMC portfolio to proxy for IST shocks. Results are very similar using the other three measures, since all measures are highly correlated in the model. In simulated data, a positive one-standard deviation IST shock leads to an increase in firm-level investment of 0.053 standard deviations. The impact of investment shocks varies in the cross-section of firms from 0.08 to 0.10 depending on the measure of growth opportunities. Similar to the data, including firm-level controls reduces the difference in investment responses among high- and low-growth firms to 0.03-0.04.

Our empirical results confirm that the firms identify as rich in growth opportunities increase their investment more following a positive IST shock relative to firms we identify as poor in growth opportunities. Furthermore, consistent with the prediction of our model, the common factor in firms' investment rates is related to the value factor.

Alternative Interpretations

Here we explore alternative interpretations of our empirical findings. To conserve space, we briefly summarize the results of additional tests and refer the reader to the Internet Appendix for details.

First, our results could be consistent with a Q-theory model, under the assumption that stock returns have a multi-factor structure. Under this alternative, a multi-factor structure in returns implies a multi-factor structure of changes in Tobin's Q, generating a similar factor structure in investment rates. We explore this alternative by estimating a modified version of (33), replacing G_f with the firm's market beta and Δz with returns to the market portfolio. The market portfolio is a major source of comovement in the cross-section of stock returns, thus under this alternative it should lead to a high degree of comovement in investment rates. We find no evidence to support this alternative. The investment of high and low market-beta firms has the same response to the market portfolio, even though the stock returns of these firms respond very differently.

Second, IMC betas may capture firms' financial constraints and not the differences in their real production opportunities. If financial constraints limit firms' ability to take advantage of new investment opportunities, the market value of such growth opportunities may be relatively low. To sharpen the interpretation of our empirical results, we replicate our empirical analysis on a sample of firms that have been assigned a credit rating by Standard and Poor's. Such firms are relatively less likely to be financially constrained, as they have access to the public debt markets. We find that our results are stronger in this subsample, indicating that our findings are unlikely to be explained by financial constraints.

Third, we estimate IMC-betas using stock return data, while the theory suggests using returns on the total firm value. To address this concern, we approximate firm-level IMC-betas by de-levering the equity-based estimates under the assumption that firms' debt is risk-free. We find that our results remain similar, regardless of whether we use book or market leverage.

Fourth, we consider whether IMC-betas capture inter-industry linkages rather than differences in growth opportunities. We construct IMC-beta quintiles based on the firm's intra-industry IMC-beta ranking, using the 30-industry classification of Fama and French (1997). Our results are slightly stronger in this case, suggesting that our findings are driven by intra- rather than inter-industry variation.

4.2 Asset Prices

Our model implies that heterogeneity in stock return exposure to IST shocks leads to cross-sectional differences in equity risk premia. Here, we evaluate the ability of our model to jointly reproduce the cross-section of risk premia and the patterns of return comovement in the data.

Risk Premia and Return Comovement

We first explore how growth opportunities are related to average returns and CAPM alphas, in both the model and in the data. We focus on portfolios of firms sorted on our two measures of growth opportunities, IMC-beta and book-to-market. We show the results in Tables 7 and 8, respectively.

[Table 7]

The top panel of Table 7 replicates the findings of Papanikolaou (2011), who shows that sorting firms into portfolios based on IMC-betas results in a declining pattern of average returns. However, as we see in the fourth row of Table 7, there is a strongly increasing pattern in market betas. As a result, the CAPM misprices the IMC-beta portfolios. The difference in average returns and CAPM alphas between the highest and lowest IMC-beta portfolios is −3.2% and −7.1%, respectively.

There is also substantial return comovement within the IMC-beta sorted portfolios. The portfolio long the top IMC-beta decile and short the bottom IMC-beta decile has a standard deviation of 25.9%, yet the market captures only a small fraction of this variation ($R^2 =$ 27.9%). Thus, the long-short portfolio has exposure to a systematic risk factor that is not captured by the market portfolio. Including the IMC portfolio captures most of this comovement, increasing the R^2 to 76%.

The bottom panel of Table 7 shows that our calibrated model reproduces these findings. The model replicates the declining pattern of risk premia across the IMC-beta deciles accompanied by the increasing pattern of market betas. Hence, the model reproduces the failure of the CAPM. The difference in average returns and CAPM alphas between the high and low IMC-beta portfolios is −3.6% and −5.7% respectively. In the model, firms with more growth opportunities have higher market exposure because the market portfolio is a linear combination of the disembodied shock x and the IST shock z. Since all firms have the same exposure to disembodied shocks x, firms with higher growth opportunities have higher market betas.

Our simulation results illustrate that the presence of two aggregate shocks generates magnitudes of return comovement comparable to the data. The long-short portfolio of high vs low IMC-beta deciles has a standard deviation of 10.5%, yet it is not spanned by the market portfolio ($R^2 = 34.6\%$).

[Table 8]

Next, we assess the ability of our model to replicate the empirical relation between stock returns and the book-to-market ratio (B/M). The top panel of Table 8 replicates the well-known value premium in our sample (see e.g., Fama and French (1992, 1993)). Sorting firms on their ratio of book-to-market equity generates large differences in average returns, but virtually no differences in market betas. As a result, the difference in average returns and CAPM alphas between value firms and growth firms is 6.1% and 5.9% respectively. Our model produces significant dispersion in risk premia between value and growth firms, and the failure of the CAPM. In simulated data, the difference in average returns and CAPM alphas between the two extreme book-to-market portfolios is 4.3% and 6.3% respectively.

An important piece of the value puzzle is the presence of the value factor. In particular, the long-short portfolio of high versus low B/M deciles has a standard deviation of 15.1% and low correlation with the market portfolio. Motivated by this pattern, Fama and French (1993) argue that value and growth firms have differential exposure to a systematic source of risk that is not captured by the market portfolio. Our model replicates this pattern in return comovement, as we see in the bottom panel of Table 8. The high minus low B/M portfolio has a standard deviation of 10.6% and is not spanned by the market portfolio ($R^2 = 31.2\%$). Thus, our model replicates the existence of the value factor, as well as the failure of the CAPM to account for the value premium in stock returns.

The model mechanism behind the dispersion in risk premia and comovement among high- and low-growth firms is that firms with different growth opportunities have different exposures to IST shocks. We verify that the market-adjusted risk premia (CAPM alphas) of firms with different growth opportunities are related to the heterogeneous exposures of these portfolios to the IST shock. Figure 1 plots the portfolio CAPM alphas versus their betas with respect to our two benchmark measures of the IST shock – changes in the relative price of equipment Δz^I (top), and returns of the IMC portfolio R^{imc} (bottom). As we see in the left panel of Figure 1, there is a strong and negative relation between the CAPM alphas of the IMC-beta portfolios and their exposures to both measures of the IST shock z.

The right panel of Figure 1 shows that the corresponding relation between CAPM alphas and IST shock exposure is similar for the cross-section of book-to-market portfolios. The two extreme book-to-market portfolios have statistically different loadings on the IMC portfolio (t-statistic of 2.4), but not on the changes in the price of equipment Δz^I (t-statistic of 1.2). However, the difference in the exposure to Δz^I between the decile portfolios 9 and 2 is statistically significant with a t-statistic of 2.1.

[Figure 1]

Our results of this section qualitatively support the view that the observed differences in risk premia and comovement across high- and low-growth portfolios can be attributed to heterogenous exposure to IST shocks. Next, we explore whether this observed difference in IST shock sensitivity can account for the observed differences in risk premia for empirically plausible values of the price of risk of IST shocks γ_z.

Market price of IST shocks

Consistent with our model, firms with different growth opportunities differ in their exposures to IST shocks and their risk premia. In this section, we estimate empirically the market prices of the IST and the disembodied technology shocks and compare the estimates to their calibrated model counterparts. Moreover, we evaluate the extent to which the observed differences in IST-risk exposures contribute to the observed differences in risk premia among stocks with different growth opportunities.

We estimate the empirical equivalent of the stochastic discount factor (9) in our model,

$$m = a - \gamma_x \, \Delta x - \gamma_z \, \Delta z, \tag{34}$$

using the generalized method of moments (GMM). We use the model pricing errors as moment restrictions, namely, we impose that the SDF in equation (34) should price the cross-section of asset returns. The resulting moment restrictions are

$$E[R_i^e] = -cov(m, R_i^e), \tag{35}$$

where R_i^e denotes the excess return of portfolio i over the risk-free rate.[10] We report first-stage GMM estimates using the identity matrix to weigh moment restrictions, and adjust the standard errors using the Newey-West procedure with a maximum of three lags. As a measure of fit, we report the sum of squared errors from the Euler equations (35).

We proxy for IST shocks with the relative price of new equipment, Δz^I. As a robustness test, we also use the change in the investment-to-consumption ratio, $\Delta \ln(I/C)$. For the neutral technology shock x, we use the change in the (log) total factor productivity in the consumption sector from Basu, Fernald, and Kimball (2006). We also consider specifications of the SDF based on portfolio returns. In particular, we use a linear combination of the market portfolio with either the IMC portfolio, or the HML portfolio, both of which span the same linear subspace as the two technology shocks x and z in the model. We normalize all shocks to unit standard deviation.

[10] Since we use portfolio returns in excess of the risk free rate, the mean of the stochastic discount factor is not identified. Without loss of generality, we choose the normalization $E(m) = 1$, which leads to the moment restrictions (35). See Cochrane (2001), pages 256-258 for details.

Table 9 shows the estimation results for the ten IMC-beta portfolios in the data (top panel) and in the model (bottom panel). The market price of the IST shock in columns (2) and (3) is negative and statistically significant. Depending on whether we approximate IST shock using equipment prices or the investment-to-consumption ratio, the point estimate of the price of risk ranges between -0.68 and -0.91. The model produces comparable but somewhat smaller estimates, -0.40 and -0.65 respectively. Thus, our calibrated price of risk γ_z is conservative relative to the data.

In addition, the cross-sectional differences in the IST risk among the IMC-beta portfolios account for a sizable portion of the differences in their average returns. Column (4) shows that the unconditional CAPM produces large pricing errors (0.37%), similar to the model in column (1) with only a disembodied productivity shock (0.41%). In contrast, adding the real proxies for the IST shock to the SDF results in a substantial reduction in pricing errors to 0.07% and 0.13% in columns (2) and (3) respectively. For comparison, adding IMC or HML portfolio returns to the market return in columns (5) and (6) results in pricing errors of 0.02% and 0.04% respectively.

[Table 9]

Table 10 shows similar results for the cross-section of ten B/M portfolios. The point estimates of the market price of IST shocks are negative and significant, and somewhat larger than those resulting from the model: the empirical estimates based on equipment prices and the investment-to-consumption ratio are -0.98% and -1.09% respectively, compared to -0.43% and -0.70% in the model. Furthermore, the pricing errors are substantially reduced by the addition of the IST shock to the stochastic discount factor. The CAPM (column (4)) results in pricing errors of 0.33%, while the two real proxies for the IST shocks above, together with the disembodied shocks, result in pricing errors of 0.12% and 0.19% respectively. For comparison, the combinations of the market portfolio with the IMC or HML portfolio returns (columns 5 and 6) produce pricing errors of 0.16% and 0.06% respectively.

Our findings suggest that differential exposure to IST shocks generates sizable differences in expected stock returns, and accounts for a significant part of the value premium. However, we should be careful when interpreting these findings. In our analysis above, we treat the estimated prices of risk as free parameters. In the case where the factors are portfolio returns, an alternative strategy is to constrain the risk premium to equal the in-sample Sharpe ratio of each portfolio. In this case, we find that the IMC portfolio does substantially worse in pricing the book-to-market cross-section. The two factor model with the market portfolio and IMC results in a sum of squared errors that is only moderately smaller than the CAPM (0.43% versus 0.65%).[11] We report the full set of results in the Internet Appendix.

[Table 10]

One important limitation of estimating the price of IST shocks using the portfolios formed on the book-to-market ratios is that such portfolios have a strong factor structure. As discussed in Lewellen, Nagel, and Shanken (2010) and Daniel and Titman (2012), this may result in spurious empirical estimates of the market prices of shocks correlated with the common factors among such portfolios. Both papers advocate the use of industry portfolios as a pragmatic solution, since returns on these portfolios do not exhibit a strong low-dimensional factor structure. We report the estimates of the SDF using the 30 Fama-French industry portfolios (Fama and French (1997)) in Table 11. The point estimates of the market price of IST shocks, when using the equipment price or the investment-to-consumption ratio as empirical proxies (columns 2 and 3) are -0.52 and -0.70 respectively, which are comparable to the estimates in Tables 9 and 10. As before, we find that the pricing errors of the SDF using real proxies for the systematic risk factors are comparable to those obtained when using portfolio returns – market, and IMC or HML.

[Table 11]

[11] Constraining the price of risk to equal the in-sample Sharpe ratio is equivalent to a time-series test, since it imposes that the SDF prices the market and IMC portfolio perfectly. See Cochrane (2001) for details.

We conclude that the market price of IST risk is negative, and the empirical estimates are consistent in magnitude with the values we use in our calibration. Moreover, the cross-sectional dispersion in average stock returns resulting from their heterogeneous exposures to IST shocks captures a sizable portion of the return spread among the portfolios sorted on the book-to-market ratio.

4.3 Cash Flows

Here, we show that our model closely replicates the empirical patterns of earnings and profitability of value and growth firms. In particular, Fama and French (1995) document that the cash flows of value and growth firms display a mean-reverting pattern. At the time of portfolio formation, growth firms are more profitable in terms of return on equity (ROE) than value firms. In the years following portfolio formation, profitability of growth firms declines whereas the profitability of value firms increases. In contrast, earnings of growth firms grow faster than those of value firms in the years after portfolio formation.

The top two panels of Table 12 replicate the findings of Fama and French (1995) for the subset of firms producing consumption goods. As we see in the bottom two panels of Table 12, our model reproduces these empirical patterns. In the model, growth firms have higher earnings-to-book than value firms at the time of portfolio formation. Similar to the data, over the next five years the average profitability of growth firms declines and the average profitability of value firms rises. This pattern arises because firm (and project) productivity is mean-reverting, hence this productivity gap dissipates over time. However, even though the average profitability of growth firms declines, growth firms accumulate capital at a faster rate than value firms. Hence, the earnings of growth firms grow faster than those of value firms of similar size.

5 Conclusion

In the last few years we have seen significant developments in structural models of the cross-sectional differences in risk premia. However, there has been far less progress in theoretical analysis of the key sources of systematic risk in stock returns. In contrast, the empirical literature has put forward a number of portfolio-based factor pricing models. However, the economic sources of return comovement behind many of these factors are not well understood.

In this paper we show that investment-specific technology shocks are an important source of systematic risk in the cross-section of stock returns. The key theoretical insight behind our analysis is that firms with abundant growth opportunities benefit more from positive investment-specific shocks than firms with limited growth opportunities, and therefore stock returns of high-growth firms have higher exposure to IST shocks. Thus, cross-sectional differences in growth opportunities generate differences in risk premia and comovement among stock returns and firm investment. In particular, our results suggest that the value factor in returns is partly driven by heterogeneous exposures of firms with different growth opportunities to the IST shocks. Our empirical findings support the model's predictions.

More generally, our analysis in this paper focuses on one type of embodied technology shocks, that is, investment-specific technical change. Embodied shocks, by definition, do not automatically benefit all firms uniformly. Thus, embodied shocks offer a promising avenue for understanding the empirical patterns of comovement and dispersion in risk premia in the cross-section of stock returns. A recent example of this line of research is Eisfeldt and Papanikolaou (2011), who consider technology shocks embodied in the human capital of firms' key employees.

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Appendix

A. Data

Macroeconomic variables

Data on the consumption deflator, consumption of non-durables and services and non-residential investment is from the Bureau of Economic Analysis. Data on the relative price of equipment is from Israelsen (2010). Data on TFP in the consumption sector is from Basu et al. (2006).

Firm-level variables

Firm-level variables are from Compustat, unless otherwise noted:

Variable	Data	Model
Investment (I)	capx	$x\, z^{-1} K_f^*$
Capital (K)	ppegt	$z^{-1}\, x\, \sum_{j \in \mathcal{J}^f} K_j$
Book Assets (A)	at	$z_t^{-1}\, x_t\, \sum_{j \in \mathcal{J}_t^f} K_j$
Operating Cash Flows (CF)	dp + item ib	$\sum_{j \in \mathcal{J}^f} y_j$
Payout	DIV+REP	$\sum_{j \in \mathcal{J}_t^f} y_{jt} - x\, z^{-1}\, K_f^*$
Market-to-Book (M/B)	V/EC	V/K
Tobin's Q (Q)	$(V + EP + D - INVT - T)/K$	V/K
Market Capitalization (V)	CRSP December market cap	V_f
Dividends (DIV)	dvc +dvp	-
Share Repurchases	prstkc	-
Book Debt (D)	dltt	-
Book Preferred Equity (EP)	pstkrv	-
Book Common Equity (EC)	ceq	-
Inventories (INVT)	invt	-
Deferred Taxes (T)	txdb	-
R&D Expenditures (R&D)	xrd	-
Cash Holdings (CASH)	che	-

Sample

We omit firms with fewer than 50 weekly stock-return observations per year, firms producing investment goods, financial firms (SIC codes 6000-6799) and utilities (SIC codes 4900-4949). In our investment regressions we also exclude firms with missing values of CAPEX (Compustat item capx), PPE (Compustat item ppent), Tobin's Q, firms in their first three years following the first appearance in Compustat, and firms with negative book values. Our sample contains 6,832 firms and 63,295 firm-year observations and covers the 1965-2008 period.

Portfolio construction

HML portfolio We construct a 2×3 sort, sorting firms first on their market value of equity (CRSP December market capitalization) and then on their ratio of Book-to-Market (see above for more details). We construct the value factor (HML) as $1/2(SV - SG) + 1/2(LV - LG)$, where SG, SV, LG and LV refer to the corner portfolios.

IMC portfolio We follow Gomes, Kogan, and Yogo (Gomes et al.) and Papanikolaou (2011) and classify firms as investment or consumption producers based on the U.S. Department of Commerce's National Income and Product Account (NIPA) tables. We classify industries based on the sector to which they contribute the most value. We use the 1997 Input-Output tables to classify NAICS industries into investment or consumption producers. We include common shares (shrcd=10,11) of all firms traded in NYSE, AMEX and NASDAQ (exchcd=1,2,3).

10 IMC-beta portfolios We sort firms annually into 10 value-weighted portfolios based on the past value of β^{imc}. We estimate β^{imc} using weekly returns. We include common shares (shrcd=10,11) of all firms traded in NYSE, AMEX and NASDAQ (exchcd=1,2,3). We restrict the sample to firms producing consumption goods, and exclude financial firms (SIC6000-6799) and utilities (SIC4900-4949). We rebalance the portfolios at the end of every calendar year.

10 BE/ME portfolios We follow Fama and French (1993) and sort firms in the consumption industry on their ratio of Book Equity (Compustat item ceq) to Market Equity (CRSP December market capitalization) into 10 portfolios. We include common shares (shrcd=10,11) of all firms traded in NYSE, AMEX and NASDAQ (exchcd=1,2,3). We use NYSE breakpoints. We restrict the sample to firms producing consumption goods, and exclude financial firms (SIC6000-6799) and utilities (SIC4900-4949). We rebalance the portfolios on June of every calendar year.

30 Industry portfolios Returns on these portfolios are available from Kenneth French's website, http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

B. Proofs and Derivations

Proof of Proposition 1. K_f is the solution to the problem:

$$\max_{K_f} A(\varepsilon_{ft}, 1) x_t K_f^{\alpha} - z_t^{-1}\, x_t\, K_f. \tag{36}$$

The first order condition is

$$\alpha\, A(\varepsilon_{ft}, 1) K_f^{\alpha-1} = z_t^{-1}. \tag{37}$$

■

Proof of Proposition 2. The value of growth opportunities depends on the NPV of future projects. When a project is financed, the value added net of investment costs is

$$\left[\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}}\right] z_t^{\frac{\alpha}{1-\alpha}} x_t\, A(\varepsilon_{ft}, 1)^{\frac{1}{1-\alpha}} = C z_t^{\frac{\alpha}{1-\alpha}} x_t\, A(\varepsilon_{ft}, 1)^{\frac{1}{1-\alpha}}. \tag{38}$$

The value of growth opportunities for firm f equals the sum of the net present value of all future projects

$$\begin{aligned} PVGO_{ft} &= \mathrm{E}_t^{\mathcal{Q}}\left[\int_t^{\infty} e^{-r(s-t)} \lambda_{fs} C z_s^{\frac{\alpha}{1-\alpha}} x_s\, A(\varepsilon_{fs}, 1)^{\frac{1}{1-\alpha}}\, ds\right] \\ &= C z_t^{\frac{\alpha}{1-\alpha}} x_t\, \mathrm{E}_t^{\mathcal{Q}}\left[\int_t^{\infty} e^{-\rho(s-t)} \lambda_{fs}\, A(\varepsilon_{fs}, 1)^{\frac{1}{1-\alpha}}\, ds\right] \\ &= C z_t^{\frac{\alpha}{1-\alpha}} x_t\, \mathrm{E}_t\left[\int_t^{\infty} e^{-\rho(s-t)} \lambda_{fs}\, A(\varepsilon_{fs}, 1)^{\frac{1}{1-\alpha}}\, ds\right] \\ &= z_t^{\frac{\alpha}{1-\alpha}} x_t\, G(\varepsilon_{ft}, \lambda_{ft}), \end{aligned}$$

where $\mathrm{E}_t^{\mathcal{Q}}$ denotes expectations under the risk-neutral measure $\mathcal{Q}$, and

$$\frac{d\mathcal{Q}}{d\mathcal{P}} = \exp\left(-\gamma_x B_{xt} - \gamma_z B_{zt} - \frac{1}{2}\gamma_x^2\, t - \frac{1}{2}\gamma_z^2\, t\right), \tag{39}$$

$\mathcal{P}$ being the physical probability measure. The second to last equality follows from the fact that λ_{ft} and ε_{ft} are idiosyncratic, and thus have the same dynamics under $\mathcal{P}$ and $\mathcal{Q}$.

Let $\mathbf{M}$ be the infinitesimal matrix associated with the transition density (Karlin and Taylor (1975)) of λ_{ft}:

$$\mathbf{M} = \begin{pmatrix} -\mu_L & \mu_L \\ \mu_H & -\mu_H \end{pmatrix}. \tag{40}$$

The eigenvalues of $\mathbf{M}$ are 0 and $-(\mu_L + \mu_H)$. Let $\mathbf{U}$ be the matrix of the associated eigenvectors, and define

$$\Lambda(u) = \begin{pmatrix} 1 & 0 \\ 0 & e^{(-\mu_L+\mu_H)\, u} \end{pmatrix} \tag{41}$$

Then

$$\mathrm{E}_t[\lambda_{fs}] = \lambda_f \cdot \mathbf{U}\, \Lambda(s-t)\, \mathbf{U}^{-1} \begin{bmatrix} \lambda_H \\ \lambda_L \end{bmatrix} = \lambda_f \cdot \begin{bmatrix} 1 + \frac{\mu_L}{\mu_L+\mu_H}(\lambda_H - \lambda_L) e^{-(\mu_L+\mu_H)(s-t)} \\ 1 - \frac{\mu_H}{\mu_L+\mu_H}(\lambda_H - \lambda_L) e^{-(\mu_L+\mu_H)(s-t)} \end{bmatrix} \tag{42}$$

and

$$
\begin{aligned}
G(\varepsilon_{ft}, \lambda_{ft}) &= C \cdot E_t \left[\int_t^{\infty} e^{-\rho(s-t)} \, \lambda_{fs} \, A(\varepsilon_{fs}, 1)^{\frac{1}{1-\alpha}} \, ds \right] \\
&= C \cdot E_t \left[\int_t^{\infty} e^{-\rho(s-t)} \, E_t[\lambda_{fs}] \, A(\varepsilon_{fs}, 1)^{\frac{1}{1-\alpha}} \, ds \right] \\
&= \begin{cases} \lambda_f \left(G_1(\varepsilon_{ft}) + \frac{\mu_L}{\mu_L + \mu_H} (\lambda_H - \lambda_L) \, G_2(\varepsilon_{ft}) \right), & \tilde{\lambda}_{ft} = \lambda_H \\ \lambda_f \left(G_1(\varepsilon_{ft}) - \frac{\mu_H}{\mu_L + \mu_H} (\lambda_H - \lambda_L) \, G_2(\varepsilon_{ft}) \right), & \tilde{\lambda}_{ft} = \lambda_L \end{cases}
\end{aligned} \tag{43}
$$

The second equality uses the law of iterated expectations and the fact that λ_{ft} is independent across firms. The functions $G_1(\varepsilon)$ and $G_2(\varepsilon)$ are defined as

$$
G_1(\varepsilon_t) = C \cdot \mathrm{E}_t \left[\int_t^{\infty} e^{-\rho(s-t)} \, A(\varepsilon_s, 1)^{\frac{1}{1-\alpha}} \, ds \right], \tag{44}
$$

$$
G_2(\varepsilon_t) = C \cdot \mathrm{E}_t \left[\int_t^{\infty} e^{-(\rho + \mu_L + \mu_H)(s-t)} \, A(\varepsilon_s, 1)^{\frac{1}{1-\alpha}} \, ds \right]. \tag{45}
$$

$G_1(\varepsilon)$ and $G_1(\varepsilon)$ will satisfy the ODEs:

$$
C \cdot A(\varepsilon, 1)^{\frac{1}{1-\alpha}} - \rho G_1(\varepsilon) - \theta_\varepsilon(\varepsilon - 1) \frac{d}{d\,\varepsilon} \, G_1(\varepsilon) + \frac{1}{2} \sigma_e^2 \, \varepsilon \, \frac{d^2}{d\,\varepsilon^2} \, G_1(\varepsilon) = 0 \tag{46}
$$

$$
C \cdot A(\varepsilon, 1)^{\frac{1}{1-\alpha}} - (\rho + \mu_H + \mu_L) G_2(\varepsilon) - \theta_\varepsilon(\varepsilon - 1) \frac{d}{d\,\varepsilon} \, G_2(\varepsilon) + \frac{1}{2} \sigma_e^2 \, \varepsilon \, \frac{d^2}{d\,\varepsilon^2} \, G_2(\varepsilon) = 0. \tag{47}
$$

■

Proof of Proposition 3. The risk premium on assets in place is determined by the covariance with the pricing kernel:

$$
\mathrm{E}_t \left[R_{ft}^{vap} \right] - r_f = -cov \left(\frac{dVAP_{ft}}{VAP_{ft}}, \frac{d\pi_t}{\pi_t} \right) = \gamma_x \sigma_x. \tag{48}
$$

Similarly, for growth opportunities:

$$
\mathrm{E}_t \left[R_{ft}^{gro} \right] - r_f = -cov \left(\frac{dPVGO_{ft}}{PVGO_{ft}}, \frac{d\pi_t}{\pi_t} \right) = \gamma_x \sigma_x + \frac{\alpha}{1 - \alpha} \gamma_z \sigma_z. \tag{49}
$$

The risk premium on growth opportunities is lower than the risk premium of assets in place as long as $\gamma_z > 0$.

Expected excess returns of the firm are a weighted average of the risk premia of the two components of its value:

$$
\mathrm{E}_t \left[R_{ft} \right] - r_f = \frac{VAP_{ft}}{V_{ft}} (\mathrm{E}_t \left[R_{ft}^{vap} \right] - r_f) + \frac{PVGO_{ft}}{V_{ft}} (\mathrm{E}_t \left[R_{ft}^{gro} \right] - r_f). \tag{50}
$$

■

Proof of Proposition 4. Profits accruing to the investment sector are

$$\begin{aligned}\Pi_t &= \phi\, z_t\, x_t \int_{\mathcal{F}} K_{ft} df \\ &= \phi \left(\int_{\mathcal{F}} A(e_{ft}, 1)^{\frac{1}{1-\alpha}} df \right) \bar{\lambda} \alpha^{\frac{1}{1-\alpha}}\, x_t\, z_t^{\frac{\alpha}{1-\alpha}} = \Gamma \cdot x_t\, z_t^{\frac{\alpha}{1-\alpha}}\end{aligned}$$

K_{ft} is the solution to the first order condition (37). Because ε_{ft} has a stationary distribution, $\Gamma = \phi\, \bar{\lambda} \alpha^{\frac{1}{1-\alpha}} \left(\int_{\mathcal{F}} A(e_{ft}, 1)^{\frac{1}{1-\alpha}} df \right)$ is a constant.

The price of the representative investment-sector firm satisfies

$$\begin{aligned}V_{It} &= \mathrm{E}_t^{\mathcal{Q}} \left[\int_t^{\infty} \exp\{-r(s-t)\}\; \phi \Pi_s\, ds \right] \\ &= \Gamma\, \mathrm{E}_t^{\mathcal{Q}} \left[\int_t^{\infty} \exp\{-r(s-t)\}\; x_s\, z_s^{\frac{\alpha}{1-\alpha}}\, ds \right] \\ &= \Gamma\, x_t\, z_t^{\frac{\alpha}{1-\alpha}} \mathrm{E}_t^{\mathcal{Q}} \left[\int_t^{\infty} \exp\left\{ \left(-r + \mu_X - \frac{1}{2}\sigma_X^2 - \frac{\alpha\, \mu_Z}{1-\alpha} + \frac{1}{2}\frac{\alpha}{1-\alpha}\, \sigma_Z^2 \right)(s-t) + \right.\right. \\ &\quad \left.\left. + \sigma_X (B_{xs} - B_{xt}) + \frac{\alpha\, \sigma_Z}{\alpha - 1} (B_{zs} - B_{zt})\, ds \right] \right\} \\ &= \Gamma\, x_t\, z_t^{\frac{\alpha}{1-\alpha}} \int_t^{\infty} \exp\left\{ \left(-r + \mu_X - \frac{\alpha}{1-\alpha}\, \mu_Z + \frac{1}{2}\frac{\alpha}{1-\alpha}\, \sigma_Z^2 + \frac{1}{2}\frac{\alpha^2\, \sigma_Z^2}{(1-\alpha)^2} \right)(s-t) \right\} ds, \\ V_{It} &= \Gamma\, x_t\, z_t^{\frac{\alpha}{1-\alpha}} \frac{1}{\rho_I},\end{aligned}$$

where

$$\rho_I = r - \mu_X + \frac{\alpha}{1-\alpha}\, \mu_Z - \frac{1}{2}\frac{\alpha}{1-\alpha}\, \sigma_Z^2 - \frac{1}{2}\frac{\alpha^2\, \sigma_Z^2}{(1-\alpha)^2} > 0. \tag{51}$$

■

Tables and Figures

Table 1: Time-series moments of IST-shock mimicking portfolios

	A. Data						B. Model	
	R^{imc}	R^{hml} (C only)	R^{imc}	R^{hml} (C only)	R^{imc}	R^{hml} (C only)	R^{imc}	R^{hml} (C only)
μ	-0.019	0.034					-0.039	0.029
Σ	0.112	-0.559					0.115	-0.978
	-0.559	0.093					-0.978	0.061
α	-0.029	0.041	-0.037	0.042	-0.007	-0.006	-0.056	0.039
	(-1.69)	(2.47)	(-2.11)	(2.59)	(-0.47)	(-0.79)	(-4.01)	(5.58)
β^{mkt}	0.225	-0.153	0.138	-0.134	0.040	0.067	0.319	-0.203
	(4.56)	(-4.17)	(2.98)	(-3.26)	(1.04)	(4.06)	(4.40)	(4.38)
β^{smb}			0.409	-0.088	0.345	0.044	0.052	0.082
			(5.69)	(-0.84)	(7.00)	(1.30)		
β^{hml}					-0.430	0.888		
					(-4.73)	(33.52)		
R^2	0.099	0.067	0.249	0.078	0.473	0.865	0.285	0.297

Table 1 shows time-series moments for the two IST-shock mimicking portfolios: IMC; and HML constructed excluding investment firms. We show mean returns μ, the matrix of standard deviations and correlations Σ, and alphas from the CAPM (columns 1-2), market and size (columns 3-4) and the Fama-French 3-factor model (columns 5-6). We use the Fama-French factors constructed using all firms, from Kenneth French's website. Columns 7 and 8 show the corresponding moments in simulated data.

Table 2: Parameter values

Parameter	Symbol	Value
Technology, aggregate shocks		
Mean growth rate of the disembodied technology shock	μ_x	0.010
Volatility of the disembodied technology shock	σ_x	0.130
Mean growth rate of IST shock	μ_z	0.005
Volatility of IST shock	σ_z	0.035
Technology, idiosyncratic shocks		
Persistence of the firm-specific shock	θ_ε	0.35
Volatility of the firm-specific shock	σ_ε	0.20
Persistence of the project-specific shock	θ_u	0.50
Volatility of the project-specific shock	σ_u	1.50
Project arrival and depreciation		
Project depreciation rate	δ	0.10
Arrival rate parameter 1	μ_λ	2.00
Arrival rate parameter 2	σ_λ	2.00
Transition probability into high-growth state	μ_H	0.075
Transition probability into low-growth state	μ_L	0.160
Project arrival rate in the high-growth state	λ_H	2.35
Stochastic discount factor		
Risk-free rate	r	0.025
Price of risk of the disembodied shock	γ_x	0.69
Price of risk of the IST shock	γ_z	-0.35
Other		
Project-level returns-to-scale parameter	α	0.85
Profit margin of the investment sector	ϕ	0.07

Table 2 summarizes the calibrated parameter values.

Table 3: Calibration

Moment	Data	Model		
		Median	5%	95%
Aggregate dividend growth, mean	0.025	0.017	-0.054	0.072
Aggregate dividend growth, volatility	0.118	0.150	0.104	0.477
Aggregate investment growth, mean	0.047	0.041	-0.041	0.068
Aggregate investment growth, volatility	0.157	0.171	0.129	0.273
Mean excess return of market portfolio	0.059	0.056	0.037	0.127
Volatility of market portfolio return	0.161	0.164	0.122	0.215
Mean return of IMC portfolio	-0.019	-0.039	-0.091	-0.012
Volatility of IMC portfolio return	0.112	0.115	0.089	0.157
Relative market capitalization of investment and consumption sectors	0.149	0.140	0.088	0.197
Firm investment rate, median	0.112	0.121	0.074	0.251
Firm investment rate, IQR	0.157	0.168	0.074	0.200
Cash flows-to-Capital, median	0.160	0.249	0.186	0.283
Cash flows-to-Capital, IQR	0.234	0.222	0.161	0.252
Tobin's Q, median	1.412	1.988	1.268	2.627
Tobin's Q, IQR	2.981	1.563	0.721	1.937
IMC-beta, median	0.683	0.731	0.456	1.074
IMC-beta, IQR	0.990	0.636	0.377	0.841
Relative firm size, median	0.201	0.701	0.679	0.721
Relative firm size, IQR	0.830	0.882	0.851	0.942

Table 3 compares sample moments to moments in simulated data. Stock return moments are estimated over the sample 1963-2008. The moments of investment growth are estimated using the series on real private nonresidential investment in equipment and software. Moments of firm-specific variables are estimated using Compustat data over the 1963-2008 period, where we report time series averages of the median and inter-quintile range (IQR) of the investment rate; cashflows over capital; market to book ratio; IMC-beta and the ratio of firm size to average firm size. Moments of dividend growth are from the long sample in Campbell and Cochrane (1999).

Table 4: Summary statistics: portfolios sorted on IMC-beta

	DATA									
β^{imc}-decile	Lo	2	3	4	5	6	7	8	9	Hi
Formation β^{imc}	-0.53	-0.08	0.19	0.40	0.61	0.82	1.04	1.32	1.74	2.59
Post-formation β^{imc}	-0.06	-0.01	-0.01	0.00	0.22	0.27	0.55	0.60	1.11	1.51
Post-formation β^{z}	-3.33	-3.06	-2.91	-2.58	-2.84	-3.38	-1.87	-2.68	-1.61	-1.02
$I/K(\%)$	10.7	10.5	10.5	10.6	11.1	11.6	11.6	12.3	13.2	14.8
Tobin's Q	1.49	1.29	1.31	1.32	1.33	1.42	1.51	1.73	2.00	2.39
$k/K(\%)$	9.3	15.9	15.7	13.5	12.1	10.1	9.1	6.9	4.7	2.7
$m/M(\%)$	8.8	15.7	14.4	12.6	10.8	11.0	9.2	7.6	6.0	3.9
CASH/ASSETS (%)	6.6	6.0	6.0	6.1	6.0	6.3	6.6	7.3	8.9	11.4
DEBT/ASSETS (%)	16.1	17.2	17.5	17.5	17.6	17.7	17.7	17.3	17.2	14.6
R&D/SALES (%)	1.4	1.2	1.2	1.3	1.5	1.5	1.8	2.4	3.7	6.0
DIV/CF (%)	9.0	16.6	18.4	18.1	17.4	16.9	13.7	10.3	7.3	2.8
	MODEL									
β^{imc}-decile	Lo	2	3	4	5	6	7	8	9	Hi
$I/K(\%)$	7.0	7.5	7.8	8.1	8.4	8.8	9.2	9.8	10.8	14.0
Tobin's Q	1.05	1.09	1.15	1.21	1.30	1.40	1.54	1.74	2.11	3.30
$k/K(\%)$	18.2	17.2	14.9	12.7	10.6	8.7	7.0	5.3	3.6	1.7
$m/M(\%)$	14.3	14.6	13.5	12.1	10.8	9.5	8.3	7.1	5.8	3.9
Formation β^{imc}	0.10	0.32	0.51	0.57	0.63	0.70	0.87	0.96	1.16	1.32
Post-formation β^{imc}	0.21	0.40	0.45	0.50	0.56	0.62	0.69	0.78	0.92	1.14

Table 4 shows summary statistics for ten portfolios of firms sorted by β^{imc}_{t-1}. β^{imc}_{t} refers to the firm's beta with the investment minus consumption portfolio (IMC) in year t, estimated using non-overlapping weekly returns within year t. We report time-series averages of the following firm characteristics: median Tobin's Q; total firm investment in the portfolio divided by the total capital stock in the portfolio, $I/K = \frac{\sum_{i\in P} I_i}{\sum_{i\in P} K_i}$; the median cash holdings over assets, $CASH/A$; the median ratio of dividends plus share repurchases over cash flows, DIV/CF; the median ratio of research and development over sales $R\&D/A$; the sum of property plant and equipment (PPE) of firms in each portfolio scaled by the total PPE, k/K; cumulative market capitalization of firms in each portfolio scaled by the aggregate market capitalization, m/M; and the median β^{imc} on which firms are sorted into portfolios.

Table 5: Response of investment rates to IST shocks

Dependent variable i_t	A. Data				
	(1)	(2)	(3)	(4)	(5)
R^{imc}_{t-1}	0.089	0.048	0.048	0.051	0.046
	(4.30)	(3.44)	(2.95)	(4.30)	(2.66)
$D(G_f)_3 \times (R^{imc}_{t-1})$		0.019	0.014	0.023	0.020
		(1.23)	(1.15)	(2.05)	(1.83)
$D(G_f)_H \times (R^{imc}_{t-1})$		0.131	0.084	0.091	0.055
		(5.53)	(5.50)	(3.06)	(2.11)
$R^2(\%)$	0.7	2.3	45.1	8.1	45.3
Growth opportunities (G_f)	-	β^{imc}	β^{imc}	M/B	M/B
Controls	N	N	Y	N	Y
Dependent variable i_t	B. Model				
	(1)	(2)	(3)	(4)	(5)
R^{imc}_{t-1}	0.053	0.026	-0.022	0.020	-0.047
	(4.40)	(4.07)	(-3.02)	(3.63)	(-3.60)
$D(G_f)_3 \times (R^{imc}_{t-1})$		0.014	-0.008	0.018	-0.002
		(3.16)	(-1.48)	(4.36)	(-1.27)
$D(G_f)_H \times (R^{imc}_{t-1})$		0.084	0.029	0.102	0.041
		(3.74)	(1.91)	(4.00)	(2.35)
$R^2(\%)$	0.3	2.5	7.4	3.5	7.9
Growth opportunities (G_f)	-	β^{imc}	β^{imc}	M/B	M/B
Controls	N	N	Y	N	Y

Table 5 shows the response of investment i_t to returns on the IMC portfolio for firms with different levels of growth opportunities G_f. We consider two measures of growth opportunities G_f: the firms's stock return beta with the IMC portfolio, β^{imc}, and the firm's ratio of market-to-book equity (M/B). $D(G_f)_i$ is a dummy quintile variable equal to 1 if firm f belongs in quintile i in year $t-1$ and zero otherwise. We show results with and without a vector of controls that includes firm-fixed effects and lagged values of log Tobin's Q, cashflows over lagged capital, log book equity over book assets, and log capital stock. See equation 33 for more details on the specification. We compute standard errors using two-way clustering by firm and by year. The top panel shows results in historical data. The sample period is 1965-2007. We exclude firms producing investment goods, financial firms (SIC6000-6799) and utilities (SIC4900-4949). The bottom panel shows results in data simulated from the model. We report the average values of the estimated coefficients and t-statistics (in parenthesis) across simulations. We simulate 1,000 samples. Each simulation sample contains 2,500 firms for 50 years. In each simulation, we exclude firms with no active projects.

Table 6: Response of investment rates and IST shocks, continued

i_t	(1)	(2)	(3)	(4)	(5)
	A. Changes in price of equipment				
Δz^I_{t-1}	0.031	-0.01	0.017	0.027	0.028
	(1.05)	(-0.43)	(0.61)	(2.10)	(1.37)
$D(G_f)_3 \times (\Delta z^I_{t-1})$		0.031	0.017	0.009	0.011
		(2.63)	(1.62)	(0.65)	(0.86)
$D(G_f)_H \times (\Delta z^I_{t-1})$		0.103	0.048	0.067	0.038
		(4.43)	(2.52)	(1.92)	(2.30)
$R^2(\%)$	0.1	1.5	44.7	8.3	45.7
i_t	B. Changes in the investment-consumption ratio				
Δic_{t-1}	0.088	0.039	0.067	0.054	0.065
	(3.85)	(1.91)	(3.20)	(3.53)	(3.39)
$D(G_f)_3 \times (\Delta ic_{t-1})$		0.038	0.02	0.006	0.006
		(3.03)	(1.57)	(0.49)	(0.41)
$D(G_f)_H \times (\Delta ic_{t-1})$		0.128	0.063	0.064	0.043
		(5.29)	(3.01)	(1.92)	(1.95)
$R^2(\%)$	0.8	2.2	45.3	7.7	43.9
i_t	C. Returns to the value factor				
$-R^{hml}_{t-1}$	0.019	-0.014	-0.002	0.005	-0.009
	(0.77)	(-0.68)	(-0.11)	(0.28)	(-0.47)
$D(G_f)_3 \times (-R^{hml}_{t-1})$		0.029	0.012	0.023	0.037
		(1.67)	(0.97)	(1.81)	(4.40)
$D(G_f)_H \times (-R^{hml}_{t-1})$		0.085	0.054	0.081	0.064
		(2.84)	(2.45)	(2.34)	(1.93)
$R^2(\%)$	0.8	2.2	45.3	7.7	43.9
Growth opportunities (G_f)	-	β^{imc}	β^{imc}	M/B	M/B
Controls	N	N	Y	N	Y

Table 6 shows the response of investment i_t to measures of the IST shocks for firms with different levels of growth opportunities G_f. We report results using three empirical proxies for the investment shock: (a) the first difference of the de-trended log quality-adjusted relative price of investment goods from Israelsen (2010); (b) changes in the log aggregate investment-to-consumption ratio; (c) negative of the returns on the HML portfolio, constructed excluding firms producing investment goods. See equation 33 in text and notes to Table 5 for more details on the specification.

Table 7: Decile portfolios sorted on IMC-beta

	Data						
β^{imc}-decile	Lo	2	3	8	9	Hi	Hi - Lo
$\mathrm{E}(R) - r_f$ (%)	5.62	5.51	6.36	4.83	4.15	2.42	-3.20
	(2.31)	(2.51)	(2.89)	(1.52)	(1.10)	(0.53)	(-0.80)
σ(%)	15.78	14.23	14.27	20.56	24.36	29.70	25.88
β^{mkt}	0.75	0.77	0.79	1.20	1.40	1.61	0.86
	(17.74)	(27.77)	(29.86)	(50.65)	(34.57)	(27.40)	(9.81)
α(%)	2.22	2.01	2.78	-0.61	-2.19	-4.88	-7.10
	(1.40)	(1.74)	(2.56)	(-0.53)	(-1.37)	(-2.10)	(-2.13)
R^2(%)	56.75	73.75	77.31	85.77	82.99	74.00	27.87
	Model						
β^{imc}-decile	Lo	2	3	8	9	Hi	Hi - Lo
$\mathrm{E}(R) - r_f$(%)	7.52	7.30	7.04	5.40	4.84	3.97	-3.55
	(3.72)	(3.51)	(3.30)	(2.14)	(1.81)	(1.34)	(-2.50)
σ(%)	14.36	14.81	15.16	17.75	18.72	20.39	10.53
β^{mkt}	0.83	0.87	0.89	1.06	1.11	1.19	0.36
	(23.51)	(30.68)	(38.90)	(77.51)	(49.93)	(31.73)	(5.15)
α(%)	2.71	2.25	1.82	-0.79	-1.65	-2.99	-5.70
	(4.82)	(5.00)	(4.93)	(-3.46)	(-4.57)	(-4.89)	(-5.05)
R^2(%)	91.27	94.69	96.56	98.91	97.63	94.49	34.59

The top panel of Table 7 reports return moments of decile portfolios sorted on IMC-beta. IMC-beta is the firm's beta with the investment-minus-consumption portfolio (IMC) in year t, estimated using non-overlapping weekly returns within year t. The construction of the IMC portfolio is detailed in Papanikolaou (2011). We restrict the sample to firms producing consumption goods, and exclude financial firms and utilities. Standard errors are computed using Newey-West with 1 lag to adjust for autocorrelation in returns. t-statistics are reported in parenthesis. We use monthly data and report annualized estimates of mean returns and CAPM alphas by multiplying the monthly estimates by 12. The market portfolio includes the investment and the consumption sector. The bottom panel reports median coefficient estimates in simulated data.

Table 8: Decile portfolios sorted on BE/ME (consumption firms)

	Data						
BE/ME-decile	Lo	2	3	8	9	Hi	Hi - Lo
$E(R) - r_f$ (%)	3.41	5.61	4.44	7.96	7.88	9.53	6.12
	(1.27)	(2.24)	(1.76)	(3.04)	(2.88)	(3.10)	(2.62)
σ(%)	17.36	16.26	16.35	16.95	17.71	19.91	15.12
β^{mkt}	1.01	0.97	0.97	0.91	0.95	1.05	0.04
	(42.71)	(47.36)	(49.48)	(24.28)	(23.45)	(22.54)	(0.67)
α(%)	-1.16	1.21	0.06	3.83	3.57	4.77	5.93
	(-1.06)	(1.46)	(0.08)	(2.63)	(2.35)	(2.67)	(2.41)
R^2(%)	84.92	90.01	87.94	72.66	72.52	69.90	0.18
	Model						
BE/ME	Lo	2	3	8	9	Hi	Hi - Lo
$E(R) - r_f$(%)	3.62	4.65	5.26	7.06	7.40	7.90	4.28
	(1.21)	(1.76)	(2.12)	(3.31)	(3.53)	(3.83)	(2.98)
σ(%)	20.49	18.49	17.48	15.18	14.91	14.67	10.65
β^{mkt}	1.19	1.09	1.04	0.90	0.87	0.84	-0.34
	(29.75)	(48.67)	(75.39)	(38.70)	(31.12)	(24.01)	(-4.71)
α(%)	-3.35	-1.76	-0.85	1.83	2.31	2.98	6.34
	(-5.16)	(-4.88)	(-3.70)	(4.94)	(5.18)	(5.33)	(5.41)
R^2(%)	93.81	97.65	98.93	96.56	94.90	91.60	31.02

The top panel of Table 8 reports return moments of ten portfolios sorted on Book-to-Market Equity. We restrict the sample to firms producing consumption goods, and exclude financial firms and utilities. We use NYSE breakpoints for portfolio assignments, following Fama and French (1993). Standard errors are computed using Newey-West with 1 lag to adjust for autocorrelation in returns. t-statistics are reported in parenthesis. We use monthly data and report annualized estimates of mean returns and CAPM alphas by multiplying the monthly estimates by 12. The market portfolio includes the investment and the consumption sector. The bottom panel reports median coefficient estimates in simulated data.

Table 9: Asset pricing - ten IMC-beta sorted portfolios

Factor price	Data (1)	(2)	(3)	(4)	(5)	(6)
Δx	1.47 [0.41, 2.52]	0.38 [-1.16, 1.93]	1.32 [0.26, 2.39]			
R^{mkt}				0.29 [0.08, 0.51]	0.41 [0.19, 0.62]	0.39 [0.17, 0.60]
Δz^I		-0.68 [-1.30, -0.07]				
Δic			-0.91 [-1.58, -0.24]			
R^{imc}					-0.29 [-0.56, -0.02]	
$-R^{hml}$						-0.42 [-0.81, -0.02]
SSQE (%)	0.41	0.07	0.13	0.37	0.02	0.04
Factor price	**Model (1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Δx	0.45 $[0.15, 0.80]$	0.70 $[0.40, 1.05]$	0.70 $[0.36, 1.13]$			
R^{mkt}				0.36 $[0.12, 0.61]$	0.81 $[0.41, 1.37]$	0.82 $[0.39, 1.45]$
Δz^I		-0.40 $[-0.78, -0.08]$				
Δic			-0.65 $[-1.46, -0.12]$			
R^{imc}					-0.87 $[-1.36, -0.54]$	
$-R^{hml}$						-0.87 $[-1.39, -0.54]$
SSQE (%)	0.13	0.00	0.00	0.30	0.00	0.00

Table 9 reports estimates of γ_x and γ_z from the model SDF: $m = a - \gamma_x\ \Delta x - \gamma_z\ \Delta z$. We use the cross-section of ten portfolios sorted on IMC-beta. Δx is the disembodied productivity shock; R^{mkt} is the market return; Δz^I is the first difference of the de-trended log quality-adjusted relative price of investment goods from Israelsen (2010); Δic is the change in the log aggregate investment-to-consumption ratio; R^{imc} is the return on the IMC portfolio (see Appendix A for details); $-R^{hml}$ is the negative of the returns on the HML portfolio, constructed excluding firms producing investment goods. The top panel presents empirical estimates using annual data in the 1965-2008 period; we report first-stage estimates and sum of squared errors (SSQE) along with 90% confidence intervals for point estimates computed using the Newey-West adjusted standard errors (three lags). The bottom panel presents estimates from 1,000 simulations, each simulation spanning 50 years. We report median point estimates across simulations, and confidence intervals computed using the 5% and 95% simulation percentiles.

Table 10: Asset pricing - ten BE/ME-sorted portfolios

Factor price	Data					
	(1)	(2)	(3)	(4)	(5)	(6)
Δx	1.54	0.27	1.13			
	[0.76, 2.32]	[-0.77, 1.31]	[0.52, 1.74]			
R^{mkt}				0.40	0.48	0.38
				[0.19, 0.62]	[0.24, 0.72]	[0.17, 0.59]
Δz^I		-0.98				
		[-1.99, -0.03]				
Δic			-1.09			
			[-2.17, -0.02]			
R^{imc}					-0.77	
					[-1.44, -0.11]	
$-R^{hml}$						-0.33
						[-0.61, -0.06]
SSQE (%)	0.37	0.12	0.19	0.33	0.16	0.06
Factor price	Model					
	(1)	(2)	(3)	(4)	(5)	(6)
Δx	0.45	0.72	0.72			
	$[0.15, 0.80]$	$[0.41, 1.07]$	$[0.37, 1.15]$			
R^{mkt}				0.36	0.83	0.82
				$[0.12, 0.62]$	$[0.42, 1.41]$	$[0.38, 1.47]$
Δz^I		-0.43				
		$[-1.01, -0.10]$				
Δic			-0.70			
			$[-1.57, -0.15]$			
R^{imc}					-0.92	
					$[-1.46, -0.56]$	
$-R^{hml}$						-0.90
						$[-1.43, -0.55]$
SSQE (%)	0.16	0.00	0.00	0.36	0.01	0.00

Table 10 reports estimates of b_x and b_z from the model SDF: $m = a - \gamma_x \Delta x - \gamma_z \Delta z$. We use the cross-section of ten BE/ME portfolios. See the footnote to Table 9 for variable definitions and the details of the estimation procedure.

Table 11: Asset pricing - Industry portfolios

Factor price	(1)	(2)	(3)	(4)	(5)	(6)
Δx	1.06	0.44	0.92			
	(3.47)	(1.76)	(3.25)			
R^{mkt}				0.37	0.43	0.37
				(3.68)	(3.94)	(3.66)
Δz^I		-0.57				
		(-3.32)				
Δic			-0.70			
			(-2.97)			
R^{imc}					-0.22	
					(-1.56)	
$-R^{hml}$						0.06
						(0.31)
SSQE	5.82	2.42	3.03	2.24	1.71	2.22

Table 11 reports estimates of b_x and b_z from the model SDF: $m = a - \gamma_x \, \Delta x - \gamma_z \, \Delta z$. We use the 30 Fama and French (1997) portfolios, excluding the 'Other' industry. See Appendix A and main text for more details, and the footnote to Table 9 for variable deifnitions. We use annual data over the 1965-2008 period; we report first-stage estimates and sum of squared errors (SSQE) along with t-statistics computed using the Newey-West procedure with three lags.

Table 12: Cash flows around portfolio formation

	A. Data										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
	1) Profitability E_t/B_{t-1}										
SG	0.213	0.212	0.217	0.229	0.240	0.250	0.221	0.231	0.226	0.225	0.226
SV	0.158	0.151	0.144	0.131	0.116	0.112	0.127	0.153	0.162	0.170	0.171
LG	0.318	0.324	0.326	0.332	0.341	0.345	0.317	0.318	0.311	0.307	0.305
LV	0.200	0.201	0.199	0.194	0.188	0.182	0.183	0.201	0.204	0.209	0.215
	2) Earnings E_t/E_t^m										
SG	0.620	0.626	0.658	0.717	0.780	1.000	1.042	1.076	1.118	1.125	1.177
SV	1.534	1.492	1.443	1.335	1.071	1.000	1.106	1.144	1.159	1.140	1.162
LG	0.895	0.895	0.919	0.926	0.968	1.000	1.007	1.019	1.060	1.081	1.101
LV	1.103	1.116	1.151	1.066	1.022	1.000	1.007	1.008	0.955	0.947	0.955
	B. Model										
	-5	-4	-3	-2	-1	0	1	2	3	4	5
	1) Profitability E_t/B_{t-1}										
SG	0.226	0.230	0.237	0.251	0.280	0.324	0.298	0.285	0.277	0.271	0.267
SV	0.229	0.223	0.214	0.197	0.168	0.166	0.194	0.211	0.221	0.227	0.231
LG	0.234	0.239	0.250	0.268	0.301	0.313	0.286	0.271	0.263	0.258	0.255
LV	0.243	0.239	0.233	0.223	0.206	0.199	0.210	0.216	0.220	0.222	0.223
	2) Earnings E_t/E_t^m										
SG	1.193	1.109	1.037	0.988	0.979	1.000	1.052	1.145	1.255	1.379	1.509
SV	1.388	1.359	1.305	1.205	1.023	1.000	1.138	1.206	1.236	1.246	1.246
LG	0.819	0.815	0.827	0.869	0.967	1.000	0.957	0.951	0.965	0.987	1.014
LV	1.133	1.144	1.140	1.109	1.034	1.000	1.018	1.013	0.996	0.975	0.951

Table 12 compares the empirical cash flow patterns of value and growth firms (Panel A) to the patterns in simulated data (Panel B). In panel 1, we calculate post-formation changes in profitability, defined as cash flows over portfolio book equity $\bar{E}^p_{t+i}/\bar{B}^p_{t+i-1}$, for size-BM portfolios formed in June of each year. Our procedure closely mimics the construction in Fama and French (1995). The four portfolios LV, LG, SV, LG refer to the corner portfolios of a 2-by-3 sort on ME and BE/ME using consumption firms only and NYSE breakpoints. $\bar{E}^p_{t+i}$ equals the sum of earnings at time $t+i$ of firms assigned to portfolio p in year t. In panel 2, earnings are measured relative to the total earnings of the market portfolio constructed using only consumption firms (E^m_t), and then standardized to one at the portfolio formation date. Hence, for portfolio p we compute $\bar{E}^p_{t+i}/\bar{E}^m_{t+i}$ and $\bar{E}^p_t/\bar{E}^m_t$ for each portfolio formation year t and lead/lag i using firms that have data in years t and $t+i$. The two ratios are then averaged separately across portfolio formation years. See the main text and Appendix A for variable definitions.

Figure 1: CAPM alphas versus IST-betas

A: TEN β^{IMC} SORTED PORTFOLIOS (Excluding investment firms)

B: TEN BOOK-TO-MARKET SORTED PORTFOLIOS (Excluding investment firms)

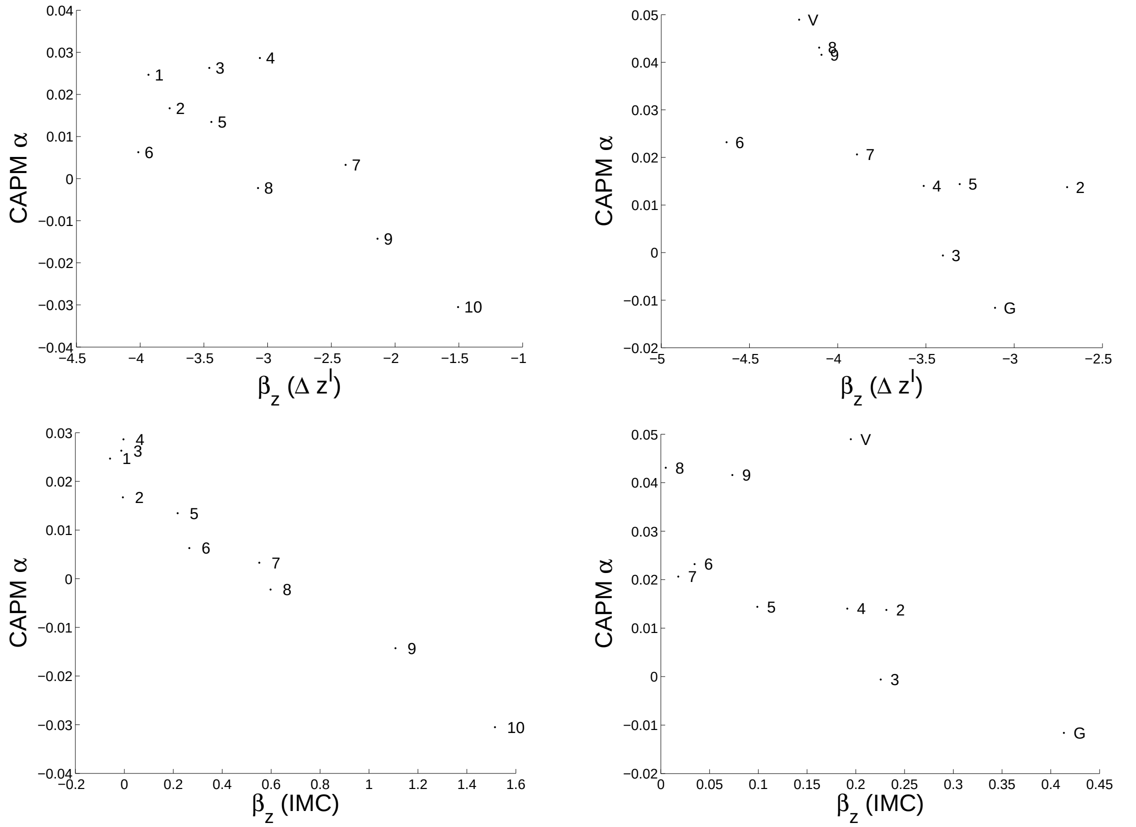

Figure 1 plots CAPM alphas versus IST-shock betas for two sets of portfolios. The left panel (A), uses ten portfolios sorted on their univariate betas with respect to the IMC portfolio, β^{IMC} (see Appendix A for the details of IMC construction). The right panel (B) uses ten portfolios sorted on their book-to-market ratio. We use two proxies for the IST shock z: (i) the negative of the changes in the de-trended log relative price of investment goods Δz^I (see the definition in Section 3.1); (ii) returns on the IMC portfolio.