Organization Capital and the Cross-Section of Expected Returns*

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Abstract

This paper studies the unique risk characteristics of organization capital. Using a stock measure of organization capital based on readily available accounting data, we find that firms with more organization capital relative to their industry peers outperform firms with less organization capital by 4.8% per year. A long short portfolio based on the ratio of the stock of organization capital to total assets within industries has a Sharpe ratio of 0.58. We develop a parsimonious model featuring what we argue are the two most salient features of organization capital, namely that it is firm specific and that it is partially embodied in firms' labor input and thus cannot be wholly owned by shareholders. The model economy illustrates the sensitivity of organization capital to economic restructuring and the resulting risk premia required for high organization capital firms.

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1 Introduction

We find that firms with more organization capital relative to their industry peers outperform firms with less organization capital by 4.8% per year. Organization capital measures the accumulated stock of organization "know-how," a collection of production and sales processes that are unique to the firm. Examples include employee incentive and training programs, distribution systems, and internal communication processes. These systems comprise an additional factor of production which is often ignored because it is difficult to measure, yet this factor is likely to be important.[1] Moreover, organization capital may have risk characteristics distinct from that of physical capital. Being intangible, organization capital lacks a physical presence and instead enhances the productivity of the match between physical capital and labor. It is highly specific and likely to depreciate substantially if the match is dissolved. Moreover, some of the rents from organization capital must be split with the labor in which it is embodied. Therefore, firms with more organization capital may be riskier and thus require higher expected returns.

We measure organization capital by accumulating firms' Selling, General, and Administrative (SG&A) Expense. Lev and Radhakrishnan (2004) argue that the SG&A expense includes most of the expenditures that generate organization capital.[2] We treat these SG&A payments as investment in organization capital and form a stock by accumulating this investment using the perpetual inventory method. Other attempts to measure organization capital have done so by measuring it as a residual from a structural model. While this methodology avoids some of the difficulties inherent in measuring intangibles, the resulting estimates are likely to be quite sensitive to the model specification. In contrast, our direct measure is model independent and recognizes that a substantial part of the SG&A expense yields long run benefits and

[1] Atkeson and Kehoe (2005) find that even for manufacturing firms payments to intangible capital constitute 8% of output. Hall (2000a) argues that e-capital arising from the use of skilled labor contributed substantially to the high value of corporate capital in the 1990's.

[2] Lev and Radhakrishnan highlight IT outlays, employee training costs, brand enhancement activities, payment to systems and strategy consultants, and the cost of setting up and maintaining internet-based supply and distribution channels as key inputs to organization capital which are included in the SG&A expense.

thus can be viewed as accumulating a durable factor in production.[3] Moreover, we find that the relationship between SG&A expenditures and firm level characteristics is remarkably similar to that of physical capital expenditures, consistent with our idea that resources allocated to this expense can be considered investment.

Using our measure of organization capital to sort firms into portfolios, we find that firms in the highest quintile outperform firms in the lowest quintile by 4.7% per year. A long short portfolio based on this sort has a Sharpe ratio of 0.57. This difference in expected returns is not explained by the CAPM, or the Fama and French (1993) three factor model, and our portfolios do not load in a systematic way on these factors. We show that our portfolios based on the contribution of organization to total capital do not vary systematically in terms of market capitalization. However, as one might expect, the high organization capital portfolio has a higher market to book ratio, a lower ratio of PP&E to total assets and lower leverage than the low organization capital portfolio.

We develop a model that captures two salient features of organization capital. First, part of the knowledge that organization capital represents is embodied in workers who can transfer this knowledge when they leave the firm, and thus these workers will effectively own some of the organization capital. Second, the specificity of organization capital means that shareholders can capture some, but not all, of the rents it accrues. Firms differ in their accumulated stock of organization capital, and in the productivity of that organization capital. Our model features two aggregate shocks. The first is a neutral technological shock that affects all capital symmetrically. The second captures the level of frontier organization capital technology. This frontier technology determines the productivity of organization capital deployed in new firms. We assume that shareholders place a high marginal value on resources available in states in which the frontier technology improves. When the frontier technology improves, resources are reallocated from old firms into new firms and this restructuring is costly. It is the differential sensitivity to the frontier technology that generates dispersion in risk premia. An improvement in the fron-

[3] The Bureau of Economic Analysis uses a similar methodology to construct a stock of Research and Development capital, see Sliker (2007).

tier technology increases workers' outside option which reduces shareholders' share of profits in existing firms. The value of firms with high levels of organization capital is more sensitive to this shock and thus these firms command higher risk premia.

We build on a growing literature which studies the properties of organization capital and highlights its unique features. To our knowledge, we are the first to study the distinguishing risk characteristics of organization capital in an economy where this input is modeled explicitly, and the first to explore the returns to organization capital using a measure of its stock constructed from accounting data.[4] Our stock measure of organization capital is built on that in Lev and Radhakrishnan (2004), who use flow data on SG&A expenses to construct more accurate estimates of corporate value. The stock measure we employ is analogous to that used by the BEA to construct a measure of R&D capital from R&D expenses. Blair and Wallman (2001), Blair and Wallman (2001), and Black and Lynch (2005) discuss the concept of organization capital and the difficulties involved in measuring it.

Our model of firms' accumulation of organization capital as a by-product of production loosely follows Atkeson and Kehoe (2005), who build on ideas in Rosen (1972), and Ericson and Pakes (1995). Atkeson and Kehoe convincingly argue that organization capital is an important input into firms' production and measure its contribution using their structural model. As in their model, our economy also features a process describing the evolution of the frontier organization capital technology, or what they call a "blueprint".[5] In contrast to their model, however, we model organization capital as being partially embodied in the workers or managers of the firm, so that shareholders cannot extract all of the rents accruing to this type of firm specific capital. We do this in the spirit of Prescott and Visscher (1980), who describe how organization capital in the form of knowledge about personnel and firm specific human capital can yield a theory of the firm with implications for firm growth and size.[6] In our model, the arrival of a new frontier technology improves

[4]See Hansen, Heaton and Li (2004) for a related study of the risk characteristics of intangible capital. They build on methods used in McGrattan and Prescott (2001), Atkeson and Kehoe (2005), and Hall (2000a; 2001) to measure intangible capital, and rely on the idea that appropriately risk adjusted investment returns to total capital should be equated across firms.

[5]See also Jovanovic and Rousseau (2001) for evidence of vintage specific organization capital.

[6]Chowdhry and Garmaise (2003) build on these ideas and develop a model of intrafirm commu-

the outside option of workers and managers who can depart and take some of the organization capital with them. In related and complementary work, Lustig, Syverson and Nieuwerburgh (2008), focus on this division of rents between shareholders and managers.[7] They explicitly model the contracting problem between shareholders and managers and deliver implications consistent with the observed rise in inequality of managerial compensation and pay for performance sensitivity, and the accompanying decrease in labor market reallocation.

Our model also aims to capture the risks inherent to organization capital during times of economic restructuring. We believe that the value of organization capital intensive firms may be particularly sensitive to periods of intense corporate reallocation and that these periods are distinct from economic downturns. In support of these ideas, Caballero and Hammour (2001; 2005), Maksimovic and Phillips (2001), and Eisfeldt and Rampini (2006) point out that restructuring and capital reallocation actually tend to be positively correlated with aggregate economic activity.[8] We also argue that investors will place a high value on resources in states where corporate restructuring must occur. Foster, Haltiwanger and Krizan (2001) show that reallocation is an integral determinant of productivity growth occurring through new plants which require a costly period of learning and selection. In general equilibrium frameworks, Papanikolaou (2008) and Eisfeldt and Rampini (2007) study the related idea that investors will place a high value on resources available in states with positive investment opportunities. In our model of organization capital, improvements in organization efficiency represent positive investment opportunities which require costly reallocation.

Our model captures several important features of organization capital which have been highlighted in the prior literature, namely, that it is intangible, firm specific,

nication to derive implications for managerial turnover and compensation.

[7]See also related work by **?**.

[8]Caballero (2007) provides a detailed exploration of the role of specific capital in economic restructuring. Davis, Haltiwanger and Schuh (1996) rigorously document the stylized facts of reallocation in the form of manufacturing job flows. Hall (2000b) explores an alternative model of restructuring, where reorganization is a form of investment which lowers contemporaneous output. Organization capital might be risky in this type of economy as well, but such risk would be well captured by market beta.

not wholly owned by firms' shareholders but embodied in the workforce, and that as a result of these unique features it will have risk characteristics distinct from those of physical capital.

2 Empirical Results

2.1 Measuring Organization Capital

As an intangible asset, organization capital is difficult to measure. This is well recognized, and previous authors have used structural models to impute the value of intangibles. Instead, we use expenditures on SG&A to construct a measure of organization capital from readily available accounting data. The U.S. GAAP definition of the Selling, General, and Administrative expense states that this item represents all commercial expenses of operation (i.e., expenses not directly related to product production) incurred in the regular course of business pertaining to the securing of operating income. The largest component of SG&A is typically labor related expenses. Investments in information technology and distribution systems, and consulting fees also constitute a substantial portion of this expense.[9] The following simple perpetual inventory equation describes how we construct our measure of the stock of organization capital:

$$O_{i,t} = (1 - \delta)O_{i,t-1} + SGA_{i,t}. \tag{1}$$

To the extent that some SG&A expenditures do not constitute investment in organization capital we will be measuring this capital with error. We deflate the SG&A expenses by the consumer price index. We are trading off this cost with the benefit that we do not rely on a specific structural model for our measure. Our measure of investment in organization capital follows Lev and Radhakrishnan (2004). Lev and Radhakrishnan (2004) and Lev (2001) present detailed arguments and examples

[9] Current accounting standards do not require companies to provide a detailed breakdown of the SG&A expense in public filings. In fact, companies often report this expense as a single line item in the company SEC filings in order to limit information disclosed to competitors. However, because the managerial discussion provides details regarding changes in the ratio of SG&A to sales over time, one can use this information to help infer the composition of the expense.

of how resources allocated to this expense yield improvements in employee incentives, internal communication systems, distribution systems, and other examples of organization capital. Our measure accumulates these expenditure and forms an organization capital stock. This stock measure recognizes that such expenditures yield long run productivity and output gains, much like capital expenditures accumulated in physical capital do.

To implement the law of motion in Equation (1) we must choose an initial stock and a depreciation rate. We follow the perpetual inventory method, and choose the initial stock according to

$$O_0 = \frac{SGA_1}{g - \delta}$$

For most of our analysis, we use a depreciation rate of 15%, which implies that past investments depreciate fairly quickly and more recent expenditures have much more impact on our measure. We choose g to match the steady-state, or average, investment rate in organization capital, which given our assumptions equals 0.25. Finally, we treat missing values in the SG&A expense as zero.

As long as organization capital is partially embedded into some of the employees and workers of the firm, we imagine such firms to be dependent on the loss of key personnel. As a check that cross-sectional differences in our measure indeed capture differences in the level of organization capital between firms, we perform the following exercise: we randomly select 5 firms, from the upper and lower quintile of organization capital to assets, and for every year between 1996 and 2005. For each of these firms we obtain their 10-K annual filings to the SEC and focus on the reported risk factors that might affect future performance.[10] Out of the 50 firms in the high organization capital to assets quintile, 48% list as a risk factor that they are dependent upon a number of key personnel, the loss of which might adversely affect future performance. In contrast, out of the 50 firms in the low organization capital to assets quintile, only 20% list the loss of key personnel as a risk factor. Assuming independent observations, a difference in means test rejects the null that the two fractions are equal with a t-statistic of 3. In addition, often the managerial discussion section

[10] Most of the time, this is part of the managerial discussion section, although sometimes it appears as a separate exhibit under "Risk Factors".

provides some examples of investment in organization capital or points out the need for such investment. In the Appendix, we provide some excerpts from the 10-K filings for a small sample of firms in the high and low organization capital quintiles.[11]

2.2 Organization Capital and Firm Characteristics

We sort firms every year into portfolios based on the share of organization capital to total assets within industries. We use the Fama and French (1997) classification to group firms into 17 industries. We choose to sort firms relative to their industry peers because the accounting rules governing the composition of the SG&A expense varies across industries. We rebalance portfolios in June every year.

Table 1 shows the median characteristic of firms in each organization capital portfolio. The first row shows the fraction of market value represented by each of the five portfolios. We the exception of the high organization capital firms, each portfolio has similar market capitalization. High organization capital firms have lower asset tangibility, defined as the ratio of physical capital (PPE) to Book Assets, lower leverage, higher Tobin's Q and lower capital-labor ratios. Perhaps surprisingly, the book to market equity ratio for the median firm does not vary substantially across portfolios, although the book to market equity ratio of the portfolio itself, which equals the value-weighted average book to market ratio, is declining for high organization capital firms. Finally, high organization capital firms tend to be firms with high operating leverage, where the latter is defined as the percentage change in income divided by the percentage change in sales.

Overall, the characteristics of firms in different organization capital portfolios is consistent with what we may expect. High organization capital firms have a lot of intangible capital, which makes borrowing more difficult and to the extent that the organization capital is properly valued by the market, these firms should also have higher Tobin's Q. Also, high organization capital should be more labor intensive. In addition, if some of the expenses that are included in SG&A are fixed costs, then it is not surprising that high organization capital firms have also higher operating

[11] We randomly selected 10 firms each from the high and low organization quintiles. After a careful read of the company 10-K filings, we have included the most relevant excerpts.

leverage.

Finally, the classification of firms across organization capital portfolios is fairly persistent. Every year, a firm will transition to another organization capital quintile with a probability of around 20%, as we show in Table 2.

2.3 Asset Pricing Tests

In this section, we explore whether differences in the level of organization capital lead to differences in risk and risk premia across firms. First, as we show in Table 3, high organization capital firms have 4.8% higher average returns per year than low organization capital firms. In addition, a portfolio that is long the high organization capital firms and short the low organization capital firms has a fairly low standard deviation of 8.2%, which implies a Sharpe Ratio greater than 0.5.

This difference in average returns is not explained by the CAPM. In fact, the high organization capital portfolio has a lower market beta than the low organization capital portfolio. The CAPM alpha of this long-short portfolio is 5.6%. However, augmenting the CAPM with a second factor, namely the long-short organization capital portfolio, prices this cross-section, as none of the alphas are statistically significant from zero. This suggests a risk-based explanation for this difference in average returns: the betas with respect to this long-short portfolio are monotonically increasing from -0.37 to 0.63. Thus, high organization capital firms tend to comove more with other high organization capital firms than with low organization capital firms.

Furthermore, the Fama and French (1993) and the Carhart (1997) models cannot explain the dispersion in risk premia due to differences in organization capital, as we show in Table 4. Adding the Fama and French (1993) SMB and HML factors to the CAPM reduces the alpha slightly to 5.5%. Adding the Carhart (1997) momentum factor reduces the alpha to 3.9% per year, but it is still statistically significant at the 1% level. In terms of factor loadings, even though the high organization capital portfolio is comprised of smaller firms and has a slight growth tilt, it is essentially uncorrelated with the SMB and HML portfolios.

2.4 Robustness Checks and Alternative Explanations

In this section we investigate the robustness of our asset pricing findings. First, we explore whether our analysis is robust to our initialization scheme, by dropping firms for which we have fewer than five previous non-missing observations of the SG&A expense. The difference in average returns between the high and low organization capital portfolios is 4.2%, and the CAPM, Fama and French and Carhart alphas are 5.1%, 4.9% and 3.3% respectively. Second, we explore the sensitivity to our results to our choice for the depreciation rate. We vary the depreciation rate from 0.1 to 0.5 and find that the difference in average returns across the high and low organization capital portfolios ranges 4.2% to 5.3%, the CAPM alphas range from 4.4% to 6.2%, the Fama and French three-factor alphas range from 5.3% to 6.2% and the Carhart four-factor alphas range from 3.8% to 4.6%.

In addition, we examine whether sorting unconditionally, as opposed to within industry, into portfolios produces similar findings. In this case, we drop the financial sector, as the accounting rules governing SG&A expenses are somewhat different. In this case, the difference in average returns between the high and low organization capital portfolios is 3.86%, and the CAPM, Fama and French and Carhart alphas are 4.6%, 5.3% and 5.4% respectively.

It is likely that maintaining a firm's organization capital may entail some fixed costs. Firms with high fixed costs will exhibit high operating leverage: for a given percentage increase in sales, they will experience a larger increase in income. In fact, Table 1 shows that our organization capital portfolios differ in terms of their operating leverage. Thus, it is possible that leverage, rather than the accumulated stock of organization capital, could be responsible for the difference in risk premia.[12] To control for the effect of operating leverage, we perform a sort based on organization capital within terciles of operating leverage (and industry). We first sort firms into three portfolios based on their degree of operating leverage (DOL). Within each DOL portfolio, we sort firms into 5 portfolios based on their ratio of organization capital over assets. We then average across the DOL sorts. Thus, the low organization

[12]For theoretical arguments relating operating leverage to risk premia see Aguerrevere (2006), Gourio (2007) and Novy-Marx (2008)

capital portfolio is contains one-third of firms with low DOL and low $\mathcal{O}/A$, medium DOL and low $\mathcal{O}/A$, and high DOL and low $\mathcal{O}/A$. This procedure produces similar spread in expected returns, and portfolio alphas. The difference in average returns between the high and low organization capital portfolios is equal to 3.1%, and the CAPM, Fama and French (1993) and Carhart (1997) alphas are 3.7%, 4.2% and 3.3% respectively. All four estimates are statistically different from zero.

A related concern is that investment in organization capital is mostly irreversible. Organization capital lacks a physical presence, and thus cannot be sold in the secondary market. This investment irreversibility creates another form of operating leverage. Firms that have accumulated a lot of irreversible capital, cannot disinvest following a bad productivity shock, implying that their stock prices will be riskier in bad times.[13] This increased sensitivity to shocks in bad times, along with a countercyclical price of risk, may lead to higher risk premia and a failure of the unconditional CAPM. In our sample, high organization capital firms have lower market betas unconditionally, but they may be riskier in bad times. We explore this possibility by estimating conditional market betas for the high minus low organization capital portfolio using weekly data. We use non-overlapping windows of 52 weekly observations to form a time-series of annual market betas. There is no evidence that the high minus low organization capital portfolio has countercyclical risk. A regression of the market beta of the high-minus-low portfolio on a NBER recession dummy has a coefficient of -0.14 with a t-statistic of -1.47.[14]

3 Model

In this section we develop a model of the formation and reallocation of organization capital. The model captures what we argue are two of the most salient features of organization capital, namely that it is firm specific and that it is partially embodied in firms' labor input and thus cannot be wholly owned by firms' shareholders.

[13] For a theoretical illustration of this mechanism see Kogan (2001; 2004) and Zhang (2005).

[14] We classify a year as a recession if more than six months of that year fall within the NBER recession dates.

3.1 Information

The information structure obeys standard technical assumptions. Specifically, there exists a complete probability space $(\Omega, \mathcal{F}, \mathcal{P})$ supporting the vector of independent Brownian motions $Z_t = (Z_t, Z_t^x, Z_t^{\varepsilon_i})$. $\mathcal{P}$ is the corresponding Wiener measure, and $\mathcal{F}$ is a right-continuous increasing filtration generated by Z.

3.2 Technology

There is a continuum of firms which produce a common output good using capital (K) and their current stock of organization capital $(\mathcal{O})$. The total output created by firm i is given by:

$$y_{i,t} = \theta_t K + \theta_t \exp(\varepsilon_{i,t}) \mathcal{O}_{it}. \tag{2}$$

For simplicity, and to focus on the distribution of organization capital, we will assume that K is constant across all firms and over time. One can think of K as land that exists in fixed supply and is needed in fixed units for production. A firm's organization capital measures the accumulated stock of firm specific knowledge about the production process and its specialized production, distribution, and sales systems, and enables the firm to produce a higher level of output for a given unit of physical capital. All firms are subject to a common technology shock θ which evolves according to

$$d\theta_t = \mu_\theta \, \theta_t \, dt + \sigma_\theta \, \theta_t \, dZ_t. \tag{3}$$

Each firm's effective organization capital depends on the efficiency of that firm's organization (ε) and the firm's stock of organization capital $(\mathcal{O})$. The efficiency of the firm's organization evolves according to

$$d\varepsilon_{i,t} = -\kappa_\varepsilon \, \varepsilon_{i,t} \, dt + \sigma_\varepsilon dZ_t^{\varepsilon_i}. \tag{4}$$

A firm's accumulated stock of organization capital grows over time via learning by doing, but also may depreciate. We have in mind that as firms' operating environment changes, some specific organization capital may actually hinder its activities.

Organization capital also grows as the firm invests more in it. The cost of increasing the stock of organization capital by $i_t\,\mathcal{O}_t$ is equal to $\theta_t\,c_o\lambda^{-1}i_t^{\lambda}\,\mathcal{O}_t$. The assumption that the marginal cost of investment in organization capital depends on the aggregate productivity, θ_t, implies that investment in organization capital will depend on the firm's idiosyncratic, but aggregate productivity.

Thus, the stock of organization capital in firm i evolves according to

$$d\mathcal{O}_{it} = (i_t - \delta)\mathcal{O}_{i,t}\,dt + \sigma_{\mathcal{O}}\,\mathcal{O}_{i,t}\,dZ_t^i \tag{5}$$

where i_t is the firm's investment rate in organization capital. Therefore, the firm has some ability to control the accumulation of organization capital, but not fully. Part of the process of accumulation is through learning by doing, and the accumulated stock of knowledge may suddenly become obsolete or depreciate. This randomness in the acquisition of organization capital is reflected in the last term of Equation 5.

The shareholders of the firm do not wholly own the organization capital, instead it is partially owned by the managers and workers of the firm. If they leave, these workers can transfer part of the accumulated knowledge and existing organization structure to a newly created firm.

Over time, new technologies which improve the frontier efficiency of organization capital emerge. In the spirit of the "blueprints" in Atkeson and Kehoe (2005), only new firms created at time t can adopt the frontier efficiency. New firms begin with efficiency $\varepsilon_{it} = x_t$ where the frontier efficiency x evolves according to

$$dx_t = -\kappa_x\,x_t\,dt + \sigma_x\,dZ_t^x. \tag{6}$$

Subsequent to formation, new firms' organization capital evolves according to (**??**).

The creation of a new firm requires K units of physical capital and will also attract organization capital away from existing firms. Here, we assume that the owners of organization capital choose to leave as a group, thus a new firm can attract organization capital from at most one existing firm.[15] At firms in which the efficiency

[15]Since organization capital features constant returns to scale and there are fixed costs of restructuring, this assumption guarantees that the number of firms remains the same.

of organization capital lags behind the frontier, the owners of the organization capital have the incentive to leave for a newly created firm. These workers can capture part of the rents from deploying the organization capital in the new firm. One can interpret this process of creation and destruction as restructuring. Old firms with low levels of organizational efficiency are restructured and transformed into new firms, after paying the restructuring cost. Following restructuring however, the division of surplus between shareholders and management may change.

Because part of the accumulated knowledge was tied to the old organization technology of the existing firm, in order to deploy the organization capital at a new firm and at the frontier efficiency, a restructuring cost must be paid. This cost can be interpreted as an interruption of the production process due to the necessary retraining of workers and adjustment of the organization structure to the new technology, or as costs from the obsolescence of existing organization capital in the new technology. A new firm that wants to deploy a level of organization capital $\mathcal{O}$ needs to pay a cost equal to

$$C(\theta, \mathcal{O}) = c\,\theta\,\mathcal{O}. \tag{7}$$

Firms cannot produce with organization capital alone but require physical capital to do so. Physical capital may be created using a linear investment technology or may be purchased from existing firms. As a result, the price of capital in this economy is equal to its marginal product.

3.3 Stochastic Discount Factor

We have described the stochastic environment of our economy under the physical measure. In order to value organization capital and firms in our economy, we will change measure. This will allow us to price risk while still discounting at the risk free rate. The change in measure will be implicitly defined by a stochastic discount factor which places more weight on states with high marginal values.

Markets are complete and there exist no arbitrage opportunities. These two assumptions imply that there exists a unique stochastic discount factor in the economy,

(π), which can be used to price any cashflow stream. In this economy, the stochastic discount factor follows

$$d\pi_t = -r\,\pi_t\,dt - \lambda_\theta\,\pi_t\,dZ_t - \lambda_x\,\pi_t\,dZ_t^x. \tag{8}$$

The parameters λ_θ and λ_x in Equation (8) determine the price of risk for the aggregate technological shock θ and the level of the frontier organization efficiency x, respectively. We assume that $\lambda_x < 0$, or in other words that improvements in the frontier technology imply that the marginal value of resources is high. Because adopting the frontier technology requires resources, whereas the output of existing firms is not affected, aggregate consumption should be lower in these states, resulting in higher marginal utility.[16] Finally, the interest rate is constant and equal to r.

As an aside, Equation (8) also implicitly defines the risk neutral equivalent probability measure as

$$\frac{d\mathcal{Q}}{d\mathcal{P}} = \exp\left(-\lambda_x Z_t^x - \lambda_\theta Z_t - \frac{1}{2}\lambda_x^2\,t - \frac{1}{2}\lambda_\theta^2\,t\right) \tag{9}$$

The dynamics of θ and x under the EMM $\mathcal{Q}$ are given by

$$d\theta_t = (\mu_\theta\; - \sigma_\theta\lambda_\theta)\theta_t\,dt + \sigma_\theta\,\theta_t\,d\tilde{Z}_t \tag{10}$$

and

$$dx_t = -\kappa_x\;(x_t - \bar{x})\;dt + \sigma_x\,d\tilde{Z}_t^x, \tag{11}$$

where $\bar{x} \equiv \frac{-\sigma_x\lambda_x}{\kappa_x}$ and $d\tilde{Z}_t = dZ_t + \lambda_\theta\,dt$ and $d\tilde{Z}_t^x = dZ_t^x + \lambda_x\,dt$ are Brownian motions under $\mathcal{Q}$.

Finally, the price of a cashflow stream X_t, can be computed by discounting these cashflows at the risk free rate under the new measure $\mathcal{Q}$ where probabilities have

[16] See Papanikolaou (2008) for a general equilibrium treatment of investment specific shocks which also require expenditures without affecting current output and thus raise the marginal value of resources.

been adjusted as follows:

$$\begin{aligned} V(X_t) &= E_t \int_t^{\infty} \frac{\pi_s}{\pi_t} X_s \, ds \\ &= E_t^{\mathcal{Q}} \int_t^{\infty} e^{-r(s-t)} X_s \, ds. \end{aligned}$$

3.4 Firm Value

Consider a firm i that has accumulated organization capital $\mathcal{O}_i$ and currently has a level of efficiency ε_{it}. First, we will value the organization capital in this firm. Next, we will show how this value is split between shareholders, and management or labor. Finally, we will compute the total value of the firm, from the shareholder's perspective, and show that firms with high organization capital earn higher expected returns in equilibrium.

3.4.1 Value of Organization Capital

First, we will value the organization capital of this firm. The value of the organization capital will equal the expectation of the discounted future cashflows while the organization capital stays with this firm under the measure $\mathcal{Q}$, plus its outside value in the event of reallocation. This value will depend on the common neutral technology shock θ, the firm's stock of organization capital $\mathcal{O}$, its organization efficiency ε_i, and the frontier organization capital technology x as follows:

$$V_{\mathcal{O}}(\theta_t, \mathcal{O}_{i,t}, \varepsilon_{i,t}, x_t) = E_t^{\mathcal{Q}} \int_t^{\tau} e^{-r\,(s-t)} \theta_s \, \mathcal{O}_{i,s} \, \exp(\varepsilon_{i,s}) \, ds + E_t^{\mathcal{Q}} e^{-r(\tau-t)} \, \overline{V}_{\mathcal{O},\tau} \tag{12}$$

Time τ is the random stopping time at which it is optimal to reallocate the organization capital to a new firm, the first term gives the cashflows generated by the firm's organization capital, and the second term, $\overline{V}_{\mathcal{O},\tau}$, denotes organization capital's outside value. Managers and workers always have the option to depart for a new firm. Moreover, we assume that owners of organization capital can extract all of the rents from organization capital at the time the firm is created.[17] Organization capital's outside option would thus equal the total value of organization capital when the firm's organization efficiency is equal to that of the frontier technology minus the cost of restructuring, or,

$$\overline{V}_{\mathcal{O},t} = V_{\mathcal{O}}(\theta_t, \mathcal{O}_{i,t}, x_t, x_t) - C(\theta, \mathcal{O}). \tag{13}$$

Note that this means, from shareholders' perspective, new firms will always be zero NPV, as organization capital captures all the rents from restructuring.

Before we compute the value of organization capital, we need to make some assumption about how investment in it is determined. We will assume that investment in organization capital is chosen to maximize total surplus, i.e. the value of organization capital.[18] This assumption can be justified through an unmodeled Coasian bargaining process between management and shareholders.

The following proposition describes how we can compute the value of organization capital in our economy.

Proposition 1. *The value of organization capital deployed in firm i equals*

$$V_{\mathcal{O}} = \theta_t \mathcal{O}_{i,t} v(\varepsilon_{i,t}, x_t) \tag{14}$$

[17] Relaxing this assumption does not alter our results qualitatively, as long as the rents which accrue to owners of organization capital when new firms are created are increasing in the total surplus generated.

[18] This assumption is not innocuous, as assuming that management or shareholders own the decision right to invest in organizational capital will have different implications about its process of accumulation. Nevertheless, this assumption makes the problem tractable as it allows us to use standard optimal control techniques. Whether management or shareholders alone own the decision right will have implications about how optimal investment responds to x. If management owns the decision right, optimal investment in organization capital will be an increasing function of x, as in the first-best case. If shareholders own the decision right, however, optimal investment will be a decreasing function of x, since shareholders will bear the costs and not the benefits. We thus intuit that allowing management to own the decision right, which is perhaps the most realistic alternative, will have the same qualitative implications.

where in the continuation region $v(\varepsilon, x)$ *is the solution to*

$$0 = \max_{i} \left[\exp(\varepsilon) - c_o \lambda^{-1} i^{\lambda} - (r + \lambda_\theta \sigma_\theta - \mu_\theta + \delta - i) \; v - \kappa_\varepsilon \, \varepsilon \, v_\varepsilon + \frac{1}{2} \sigma_\varepsilon^2 v_{\varepsilon\varepsilon} - \kappa_x \, (x - \overline{x}) v_x + \frac{1}{2} \sigma_x^2 \, v_{xx} \right] \tag{15}$$

The continuation region is defined by $\varepsilon_{i,t} \geq \varepsilon^*(x_t)$, *where* $\varepsilon^*(x)$ *solves*

$$v(\varepsilon^*(x), x) = v(x, x) - c \equiv \overline{v}(x) \tag{16}$$

and

$$\rho(\varepsilon, x) = r + \lambda_\theta \sigma_\theta - \mu_\theta + \delta - i(\varepsilon, x). \tag{17}$$

Investment in organization capital is

$$i(\varepsilon, x) = \left(\frac{v(\varepsilon, x)}{c_o} \right)^{\frac{1}{\lambda - 1}} \tag{18}$$

Proof: The value of organization capital deployed in firm i equals

$$\begin{aligned} V_{\mathcal{O}} &= E_t^{\mathcal{Q}} \int_t^{\tau} e^{-r\,(s-t)} \theta_s \, \mathcal{O}_{i,s} \, \exp(\varepsilon_{i,s}) \, ds + E_t^{\mathcal{Q}} e^{-r(\tau - t)} \, \overline{V}_{\mathcal{O},\tau} \\ &= \theta_t \, \mathcal{O}_{it} \, E_t^{\mathcal{Q}} \int_t^{\tau} e^{-\int_t^s \rho(\varepsilon_{iu}, x) \, du} \exp(\varepsilon_{i,s}) \, ds + E_t^{\mathcal{Q}} e^{-r(\tau - t)} \, \overline{V}_{\mathcal{O},\tau} \end{aligned}$$

where

$$\rho(\varepsilon, x) = r + \lambda_\theta \sigma_\theta - \mu_\theta + \delta - i(\varepsilon, x).$$

The first equality holds by the law of iterated expectations and the definition of ρ follows from our description of the stochastic processes for θ and $\mathcal{O}$. We guess that the value of organization capital can be written as:

$$V_{\mathcal{O}} = \theta_t \mathcal{O}_{i,t} v(\varepsilon_{i,t}, x_t).$$

Given that the supply of capital is perfectly elastic, the owners of organization capital will extract all of the rents it accrues in newly created firms. Thus, we know that at time t organization capital's outside option is given by the total value of the organization capital in the new firm, where it will operate at the frontier efficiency, less the adjustment cost necessary to retool the old organization capital. This outside option can be written as:

$$\theta_t \mathcal{O}_{i,t} v(x_t, x_t) - C(\theta_t, \mathcal{O}_{i,t}).$$

Thus, comparing the inside and outside option, we see that organization capital will only be reallocated to a new firm if

$$v(\varepsilon_{i,t}, x_t) < v(x_t, x_t) - c.$$

In the continuation region, the value of organization capital including current cash-flow is a martingale, and thus v is the solution to (15), which verifies our guess. Because $v(\varepsilon_{i,t}, x_t)$ is monotonically increasing in ε, continuation will be efficient as long as $\varepsilon_{i,t} \geq \varepsilon^*(x_t)$. At the threshold $\varepsilon^*(x_t)$ defined by (16), the value of organization capital inside the firm equals exactly its value in a new firm minus installation costs, at which point the owners of organization capital are indifferent between continuation and reallocation.

Finally, in the continuation region, the firm will choose investment to maximize $i\, v - c_o \lambda^{-1}\, i^{\lambda}$, which leads to (18). QED

3.4.2 Rents to Owners of Organization Capital

At time t, organization capital's outside option $\overline{V}_{\mathcal{O},\tau}$ is given by

$$\theta_t\, \mathcal{O}_{i,t}\, v(x_t, x_t) - C(\theta_t, \mathcal{O}_{i,t}) = \theta_t\, \mathcal{O}_{i,t}\, \overline{v}(x_{i,t}).$$

If the firm pays the owners of organization capital a flow payment of $w_t\, dt$ as long as it stays within the firm, the present value of these payments plus the organization capital's outside option will equal

$$W_t = E_t^{\mathcal{Q}} \int_t^{\tau} e^{-r\,(s-t)} w_s ds + E_t^{\mathcal{Q}} e^{-r(\tau - t)}\, \overline{V}_{\mathcal{O},\tau}. \tag{19}$$

In order for the organization capital to remain with the firm, its owners must receive, in present value terms, at least the value of their outside option. In addition, we assume that the firm cannot commit to pay workers more than their outside option.[19] This means, that in every state of the world, the present value of all future payments to workers must equal their outside option,

$$W_t = \theta_t \, \mathcal{O}_{i,t} \, \overline{v}(x_{i,t}). \tag{20}$$

We will use these two properties of the payments to organization capital, described in Equations (19) and (20), to derive the process for the instantaneous cashflow to labor, $w_t \, dt$. Intuitively, the requirement that the manager's continuation value equals his outside option in every state of the world pins down W_t and W_{t+dt}. The firm will then compensate the manager in such a way as to satisfy this and to make $W_t = w_t + e^{-r\,dt} E_t^{\mathcal{Q}} W_{t+dt}$ hold always. The flow payments to organization capital are described in the following proposition:

Proposition 2. *The owners of organization capital receive a flow payment* $w_t \, dt$ *every period, given by*

$$w_t = \left(\rho(\varepsilon_{i,t}, x) + \kappa_x \, (x_t - \bar{x}) \, \frac{\overline{v}_x}{\overline{v}} - \frac{1}{2} \, \sigma_x^2 \, \frac{\overline{v}_{xx}}{\overline{v}} \right) W_t, \tag{21}$$

where $\overline{v}(x)$ *is defined in Equation (16).*

Proof: Lack of commitment on both sides implies that $W_t = \overline{V}_{\mathcal{O}} = \theta_t \, \mathcal{O}_{i,t} \, \overline{v}(x_{i,t})$ must always hold. Under $\mathcal{P}$, an application of Ito's Lemma implies that organization

[19] The assumption that workers receive no more than the present value of their outside option simplifies our analysis. Given that we effectively assume that shareholders and laborers are diversified, i.e. their marginal utility does not depend on ε_i, allowing for firm commitment would yield an indeterminacy in terms of payment plans. Lustig, Syverson and Van Nieuwerburgh (2008) consider risk averse managers and provide an interesting analysis of the division of the surplus over and above workers' outside option following Thomas and Worall (1988).

capital's outside option for $t < \tau$ evolves according to:

$$\begin{aligned} d\overline{V}_{\mathcal{O}} &= (\mu_\theta + g(\varepsilon_{i,t}) - \delta)\overline{V}_{\mathcal{O}}\, dt + \sigma_\theta\, \overline{V}_{\mathcal{O}}\, dZ_t - \kappa_x\, x_t\, \overline{V}_{\mathcal{O}}\, \frac{\overline{v}_x}{\overline{v}}\, dt + \\ &\quad + \overline{V}_{\mathcal{O}} \frac{\overline{v}_x}{\overline{v}} \sigma_x\, dZ_t^x + \frac{1}{2}\sigma_x^2 \frac{\overline{v}_{xx}}{\overline{v}}\, \overline{V}_{\mathcal{O}}\, dt. \end{aligned}$$

In the event where separation or restructuring occurs, organization capital has exercised its option to leave. At this point, labor can extract no more rents from the old firm and thus receives no more payments. The martingale representation theorem and Equation (19) imply that under $\mathcal{Q}$, and as long as $t < \tau$,

$$dW_t = (r\, W_t - w_t)\, dt + b_x\, d\tilde{Z}_t^x + b_i\, dZ_t^i + b_\theta\, d\tilde{Z}_t.$$

Given the change of measure defined by Equations (10) and (11), under $\mathcal{P}$ we have that

$$dW_t = (r\, W_t - w_t)\, dt + b_x\, (dZ_t^x + \lambda_x\, dt) + b_i\, dZ_t^i + b_\theta\, (dZ_t^\theta + \lambda_\theta\, dt).$$

The shareholders will choose a flow payment $w_t\, dt$ and sensitivities b_x, b_i and b_θ, to compensate organization capital to make sure that $W_t = \overline{V}_{\mathcal{O}}$ holds in every state of the world. This boils down to ensuring that $d\, W_t = d\, \overline{V}_{\mathcal{O}}$ for all t and realizations of the Brownian shocks $d\, Z_t^\theta$, $d\, Z_t^x$ and $d\, Z_t^{\varepsilon i}$. Matching coefficients yields:

$$\begin{aligned} b_\theta &= \sigma_\theta\, W_t \\ b_i &= 0 \\ b_x &= \sigma_x\, \frac{\overline{v}_x}{\overline{v}}\, \overline{V}_{\mathcal{O}} \\ r\, W_t - w_t + b_x\, \lambda_x + b_\theta \lambda_\theta &= (\mu_\theta + g(\varepsilon_{i,t}) - \delta)\, \overline{V}_{\mathcal{O}} - \kappa_x\, x_t\, \frac{\overline{v}_x}{\overline{v}}\, \overline{V}_{\mathcal{O}} + \frac{1}{2}\sigma_x^2\, \frac{\overline{v}_{xx}}{\overline{v}}\, \overline{V}_{\mathcal{O}} \end{aligned}$$

Finally, combining these four equations yields Equation (21). QED

3.4.3 Rents to Shareholders

In this section we derive the value of the entire firm from the shareholders' perspective. Shareholders have full ownership of the physical capital stock, but also derive some rents from organization capital. The value of the firm to the shareholders equals the present value of output minus the present value of payments to the owners of organization capital plus the value of the firm to shareholders after restructuring

$$V_{firm}(t) = E_t^{\mathcal{Q}} \int_t^{\tau} e^{-r(s-t)} \left(y_s - w_s\right) ds + E_t^{\mathcal{Q}} e^{-r(\tau-t)} V_{\mathcal{K}}(\tau) \tag{22}$$

The value of the firm's physical capital equals the present value of all cashflows generated by it:

$$V_{\mathcal{K}}(t) = E_t^{\mathcal{Q}} \int_t^{\infty} e^{-r(s-t)} \theta_s K = \frac{1}{r + \lambda_\theta \sigma_\theta - \mu_\theta} \, \theta_t \, K \equiv q \, \theta_t \, K \tag{23}$$

In addition to $V_{\mathcal{K}}$, shareholders also capture the difference between the value of the organization capital in the firm and its outside option. Therefore, the total value of the firm, equals

$$V_{firm}(t) = q \, \theta_t \, K + \theta_t \, \mathcal{O}_{i,t} \left(v(\varepsilon_{i,t}, x_t) - \overline{v}(x_t)\right) \tag{24}$$

The following proposition describes the properties of the cross section of expected returns, and shows that in this economy variation in expected returns is driven by variation in organization capital.

Proposition 3. *Expected returns for firm i will be equal to*

$$E_t \left[\frac{dV_{firm}}{V_{firm}} + \frac{y_t - w_t}{V_{firm}} \, dt \right] = \left(r + \lambda_\theta \, \sigma_\theta + \lambda_x \, \sigma_x \, \lambda(\varepsilon_{i,t}, x_t) \, \frac{\frac{\mathcal{O}_t}{K} (v(\varepsilon_t, x_t) - \overline{v}(x_t))}{q + \frac{\mathcal{O}_t}{K} (v(\varepsilon_t, x_t) - \overline{v}(x_t))} \right) dt \tag{25}$$

where

$$\lambda(\varepsilon, x) = \frac{v_x(\varepsilon, x) - \overline{v}_x(x)}{v(\varepsilon, x) - \overline{v}(x)}$$

Proof An asset's expected return in excess of the risk free rate is equal to the difference of its drift between the $\mathcal{P}$ and $\mathcal{Q}$ measures. Thus, applying Ito's lemma to

Equation (24) and computing the difference in drift terms under $\mathcal{P}$ and $\mathcal{Q}$ yields

$$\begin{aligned}
\mu_i V_{firm}\, dt - r\, V_{firm}\, dt &= \lambda_\theta \sigma_\theta \theta_t \frac{\partial V_{firm}}{\partial \theta}\, dt + \lambda_x \sigma_x \frac{\partial V_{firm}}{\partial x}\, dt \\
&= \lambda_\theta\, \sigma_\theta\, V_{firm}\, dt + \lambda_x\, \sigma_x \left(\theta_t \mathcal{O}_t (v_x(\varepsilon_t, x_t) - \overline{v}_x(x_t))\right)\, dt \\
&= \lambda_\theta\, \sigma_\theta\, V_{firm}\, dt + \lambda_x\, \sigma_x \frac{\frac{\mathcal{O}_t}{K}(v_x(\varepsilon_t, x_t) - \overline{v}_x(x_t))}{q + \frac{\mathcal{O}_t}{K}(v(\varepsilon_t, x_t) - \overline{v}(x_t))} V_{firm}\, dt
\end{aligned}$$

QED.

Risk premia are determined by factor loadings times the price of risk. All firms have the same exposure to the aggregate productivity shock (θ). Therefore, any difference in risk premia across firms arises due to differential sensitivity to the frontier shock (x). The value of the rents that shareholders can extract from organization capital falls with x, since the frontier shock increases organization capital's outside option. Thus, $\lambda(\varepsilon, x) < 0$. As long as high x states are also high marginal valuation states, ($\lambda_x < 0$), this implies that firm's risk premia will be an increasing function of $\mathcal{O}/K$.

3.5 Numerical Solution

We solve the model numerically, where the computational details are described in the Appendix. Our choice of parameter values is shown in Table 5. We set $K = 1$. We pick the depreciation rate to equal 15%, which is consistent with our empirical implementation. We set the risk-free rate to equal 4%, which is slightly higher than the historical average (3%). This ensures that value function does not explode at the edges of our computational grid. We set the growth rate of θ to equal 0.5% and its standard deviation to equal 15%. The latter number ensures that the volatility of stock returns matches the data. We pick the parameters of the investment process, $c_o = 3000$ and $\lambda = 3.5$, along with $\sigma_{\mathcal{O}} = 0.2$ to generate sufficient dispersion in organization capital in the data. We choose $\sigma_x = 0.2$ and $c = 5$ to match the standard deviation of the high-minus-low organization capital portfolio. Our assumptions about the mean reverting parameters κ_ε and κ_x imply that firm-specific productivity shocks have a half life of 1.6 years, whereas the frontier technology shock has a half-life of 6.6 years. Finally, we pick the risk prices to equal $\lambda_\theta = 0.2$ and $\lambda_x = -0.85$. The first helps match the average level of stock returns, whereas the latter helps match the difference in average returns between the high and low organization capital portfolio.

The assumption that $\lambda_x < 0$ implies that high x states are high marginal valuation states. This is an important assumption which drives the sign of risk premia in the model. This assumption can be justified, because reallocation does not provide immediate benefits yet entails a cost. In general equilibrium this will imply that the part of output that can be consumed will necessarily fall, resulting in higher marginal utility of consumption. Here, note that this mechanism is similar in spirit to Papanikolaou (2008), where real investment opportunity shocks result in high marginal valuation states.

We plot the solution of our model in Figure (1). The top left panel graphs values of $v(\varepsilon_t, x_t)$ and shows that this value is increasing in both firm specific efficiency and the frontier efficiency. This value is the value of the cashflows generated by organization capital while it remains in the firm plus the value of organization capital's outside option. The top right panel of figure (1) graphs the value of organization capital's outside option as a function of the frontier organization efficiency and shows that this outside option is increasing. The bottom left panel graphs the lowest firm specific organization efficiency for which organization capital remains with the firm and this cutoff also increases with improvements to the frontier efficiency. Finally, the bottom right panel of figure (1) graphs $v(\varepsilon_t, x_t) - \bar{v}(x)$ and shows that while this value is increasing in ε it is decreasing in x due to the subtraction of the outside option. This illustrates why the value to shareholders of firms with large stocks of organization capital is sensitive to shocks to the frontier technology. The payments to organization capital depend on outside options to work at this frontier efficiency and this decreases the value to shareholders.

3.6 Numerical Simulations

Here, we compare the implications of our model to the data described in Section 2. We simulate 2000 firms, at a monthly frequency, for 50 years. We sort firms into 5 portfolios based on their ratio of organization capital to physical capital (K) and replicate the results of Tables 1 and 3 in the simulated data.

We present the results in Table 6. Given our choice of parameters, we can match the dispersion in the ratio of organization capital in the data. In the simulated data, organization capital accounts for 57% of the valuation of the high organization capital portfolio, compared to 4% for the low organization capital portfolio.

Interestingly, in the model, as in the data, the high organization capital portfolio exhibits higher operating leverage.[20] The intuition for this result is that part of firms' costs, namely the payout to management, w, is relatively insensitive to the firm-specific productivity of organization capital, ε. Thus, with respect to ε, high organization capital firms have higher operating leverage. In contrast however, w is also a function of x, whereas current output is not. This tends to produce the opposite effect. In our parameterizations, given that $\sigma_\varepsilon > \sigma_x$, this implies that most of the variation in firm-level profitability comes from ε and not from x. The net result is that, in our parametrization, hight organization capital firms also have higher operating leverage.

In terms of asset prices, the model closely replicates the pattern found in the data. The difference in average returns between high and low organization capital firms is 4.7% per year, and in the model, the CAPM fails to price the cross-section. The CAPM alpha of the high-minus-low portfolio equals 3.5%. Augmenting the CAPM with a second factor, the high-minus-low organization capital portfolio prices the cross-section of stock returns, as none of the alphas are statistically different from zero.

[20] In the simulated data, we measure operating leverage as $\Delta \ln(Y - w - c_o \lambda^{-1} i^{\lambda} \theta \mathcal{O})/\Delta \ln Y$.

4 Model Predictions

In this section we explore some of the testable implications of the model. In particular, we explore the model's predictions about firm's investment behavior in organization capital as well as the differential sensitivity of firm returns to capital reallocation shocks.

4.1 Organization Capital and Reallocation

In the model, the mechanism that leads high organization capital firms to have higher risk premia than low organization capital firms is that they fall in relative value when the frontier level of technology, x is high. However, testing this prediction empirically is somewhat difficult, given the fact that x is largely unobservable. Nevertheless, periods when x is high should be periods of high reallocation, and the latter can be measured empirically.

We consider two proxies for x: the turnover rate in Property, Plant and Equipment (PPE) series constructed in Eisfeldt and Rampini (2006), and the number of new IPOs, from Ibbotson, Sindelar and Ritter (1994), excluding penny stocks, units and closed end funds. Given that both series are fairly persistent, we obtain innovations from an AR1 model. The estimated AR1 coefficients for the two series are 0.91 and 0.73 respectively. Figure 2 plots returns of the portfolio which is long high organization capital firms and short low organization capital firms versus the two innovation measures of reallocation. The correlation of the returns on the high-minus-low organization capital portfolio with the turnover rate in PPE equals -31.8%, with a t-statistic of -1.96, whereas the correlation with the number of new IPOs is -26.1%, with a t-statistic of -2.09.

These patterns imply that firms with a lot of organization capital perform relatively poorly in periods of restructuring, consistent with our model.

4.2 Investment in Organization Capital

Our model makes specific implications about the process of investment in organization capital. Equation (18) shows that the investment rate in organization capital is increasing in the total value of organization capita, $v(\varepsilon, x)$. As can be seen in Figure 1, $v(\varepsilon, x)$ is increasing in both ε and x. The response to x is particularly interesting because it is an systematic shock and will thus affect the aggregate investment rate in organization capital.

We investigate this prediction of the model in the data. We proxy for x with the accumulated return on the low-minus-high organization capital portfolio, $R^x_t = \sum_{l=0}^{3} R^1_{t-l} - R^5_{t-l}$.[21]. This is a direct implication of our model, since the stock price of high organization capital firms falls in value relative to low organization capital firms when x increases. We control for proxies of the firm-specific productivity shock, ε, by including standard measures of firm-profitability: return on assets, sales growth and Tobin's Q. We adjust the denominator in the latter by adding the stock of organization capital to the value of book assets.

We estimate

$$i^{oc}_{it} = a_0 + a_1\, R^x_{t-1} + a_2\, Q_{it-1} + a_3\, \Delta y_{it-1} + a_4\, ROE_{it-1} + bX_{it-1} + \gamma_i + u_{it}, \qquad (26)$$

where $i^{oc}_{it} = \frac{SGA_{it}}{O_{it-1}}$ is the investment rate in organization capital, y is log sales (Compustat item sale), ROE refers to cashflows over book assets (Compustat item dp plus ib over at). X is a vector of controls which includes industry fixed effects, lagged investment rate, leverage and the ratio of organization capital stock to book assets. We include the latter two to control for the possibility of debt overhang or decreasing returns to scale, even though they are both outside the model. We normalize all variables to zero mean and unit variance. Finally, we drop observations where $i^{oc} > 10$ and $ROE > 2$, leaving us with 88,860 firm-year observations. We cluster the standard errors by firm and year.

Table 7 shows the results. Consistent with our model, the coefficient on R^x is positive and statistically significant and ranges from 0.034 to 0.052 depending on

[21] Adjusting the lag-length between 1 and 6 has little quantitative impact on our results

controls. The coefficients a_2-a_4 are also positive and statistically significant. Individual firms invest more in organization capital following low realizations of returns of high versus low organization capital firms (high x). In addition, firms invest more in organization capital when they are more profitable, both in terms of ROE and sales growth, and when the value of organization capital is higher. Investment in organization capital is also fairly persistent and decreases with the amount of leverage the firm has.

We show that our model can reproduce these empirical results. We estimate Equation 26 in simulated data from the model. We simulate 2000 firms for 50 years from the model and report median coefficients and t-statistics across 2000 simulations in Table 8. Our model can reproduce our findings, at least qualitatively. The coefficients across Tables 7 and 8 are close in magnitude. The coefficient on R^x is positive and statistically significant and ranges from 0.081 to 0.094, depending on controls. As in the data, the coefficients a_2-a_4 are also positive and statistically significant, whereas investment is fairly persistent.

5 Conclusion

In this paper we have argued that organization capital has risk characteristics distinct from those of physical capital, and that the risk inherent in this type of specific, intangible, capital requires significant risk premia. We document a sizable return premium for firms with substantial stocks of organization capital, and show that the excess return to a portfolio which is long high organization capital firms and short low organization capital firms cannot be explained by standard risk factors. The model economy we construct attributes the risk of organization capital to the fact that it is highly firm specific and cannot wholly be owned by shareholders.

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Tables

Table 1: Summary Statistics: 5 Portfolios Sorted on OC/A

Portfolio	Lo	2	3	4	Hi
MKCAP (% of CRSP total)	19.7%	17.0%	17.6%	19.2%	8.7%
Organization Capital to Book Assets	0.279	0.728	1.160	1.679	2.811
Physical Capital to Book Assets	0.297	0.242	0.221	0.211	0.192
Book-to-Market Equity	0.732	0.726	0.741	0.745	0.766
Book-to-Market Equity (value-weighted)	0.638	0.539	0.509	0.464	0.536
Tobin's Q	1.217	1.267	1.281	1.272	1.281
Debt-to-Assets	0.266	0.215	0.186	0.170	0.154
Capital-to-Labor (log)	3.368	3.093	2.929	2.780	2.455
Residual Output	-0.099	-0.022	0.000	0.020	0.057
Investment to Capital (organization)	0.300	0.280	0.256	0.233	0.198
Investment to Capital (physical)	0.218	0.229	0.227	0.229	0.226
Degree of Operating Leverage	1.036	1.103	1.125	1.172	1.294

Table 1 shows time-series averages of characteristics of the 5 portfolios sorted on organization capital over Book Assets (Compustat item at) relative to the industry. We use the 17 industry classification of Fama and French (1997). Organization capital is defined as $O_{i,t} = (1-\delta)\, O_{i,t-1} + SGA_{i,t}$, where SGA is Selling, General and Administrative Expenses (Compustat item xsga). We chose $\delta = 0.15$. In the portfolio sorts, we only include firms where $O_{i,t} > 0$. We use medians as measures of portfolio characteristics except the first row which shows each portfolio's market capitalization as a fraction of the total. Tobin's Q is computed as December market capitalization plus book value of debt plus book value of preferred stock minus book value of common equity, inventories and deferred taxes, divided by book assets. Physical Capital refers to Copmustat item ppent, Book Equity to item ceq, Debt is item dltt+item dlc, and Labor is item emp. We estimate operating leverage by the ratio of the change in Operating Income (item dp+item ib) to Sales (item sale). We define residual output as the residual from $\ln Sales_{it} = a_{It} + \beta_{It} \ln PPE_{it} + \gamma_{It} \ln Labor_{it} + u_{it}$, where the coefficients are allowed to vary by industry (I) and time (t).The sample period is January 1970 to December 2007.

Table 2: Portfolio Transition Probabilities: 5 Portfolios sorted on $\mathcal{O}/A$

		Sort(t-1)				
		Lo	2	3	4	Hi
	Lo	80.3%	9.4%	1.3%	0.5%	0.3%
	2	17.6%	66.4%	12.3%	1.9%	0.6%
Sort(t)	3	1.5%	21.1%	63.3%	12.3%	1.7%
	4	0.4%	2.53%	20.9%	68.2%	10.3%
	Hi	0.2%	0.6%	2.2%	17.2%	87.1%

Table 2 plots the transition probabilities across portfolio quintiles. Stocks are sorted into portfolios based on Organization Capital over Book Assets (Compustat item at) relative to the industry. We use the 17 industry classification of Fama and French (1997). Organization capital is defined as $O_{i,t} = (1-\delta)\, O_{i,t-1} + SGA_{i,t}$, where SGA is Selling, General and Administrative Expenses (Compustat item xsga). We chose $\delta = 0.15$. In the portfolio sorts, we only include firms where $O_{i,t} > 0$. Sample period is January 1970 to December 2008.

Table 3: Asset Pricing: 5 portfolios sorted on $\mathcal{O}/A$

Sort	1	2	3	4	5	5m1
Excess Return (%)	3.97	4.37	6.34	6.73	8.73	4.77
	(1.39)	(1.49)	(2.38)	(2.71)	(3.46)	(3.61)
σ (%)	17.70	18.22	16.53	15.43	15.67	8.21
α(%)	-1.60	-1.30	1.15	1.96	4.01	5.61
	(-2.30)	(-1.63)	(1.78)	(2.64)	(4.30)	(4.37)
β_{MKT}	1.09	1.11	1.01	0.93	0.92	-0.16
	(68.99)	(49.52)	(68.73)	(43.28)	(37.68)	(-5.19)
R^2(%)	94.64	92.52	93.99	91.12	86.89	10.15
α(%)	0.49	0.02	0.94	0.37	0.49	
	(0.98)	(0.02)	(1.46)	(0.55)	(0.98)	
β_{MKT}	1.02	1.07	1.02	0.98	1.02	
	(85.52)	(53.52)	(73.30)	(56.93)	(85.52)	
β_{5m1}	-0.37	-0.23	0.04	0.28	0.63	
	(-16.99)	(-5.08)	(1.21)	(8.18)	(28.54)	
R^2(%)	97.33	93.52	94.02	93.16	96.59	

Table 3 shows asset pricing tests for 5 portfolios sorted on organization capital over assets (Compustat item at) relative to the industry. We classify firms into 17 industries, according to Fama and French (1997). The portfolio 5m1 refers to the portfolio long the high organization capital firms and short the low organization capital firms. Organization capital is defined as $O_{i,t} = (1-\delta)\,O_{i,t-1} + SGA_{i,t}$, where SGA is Selling, General and Administrative Expenses (Compustat item xsga). We chose $\delta = 0.15$. In the portfolio sorts, we only include firms where $O_{i,t} > 0$. The sample period is January 1970 to December 2008. t-statistics, reported in parenthesis, are computed using the Newey-West estimator allowing for 1 lag of serial correlation in returns. All numbers are annualized by multiplying by 12.

Table 4: Asset Pricing: 5 portfolios sorted on $\mathcal{O}/A$

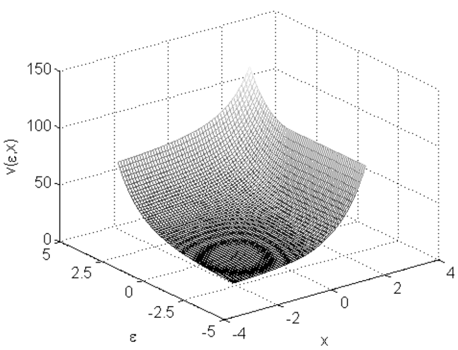
Sort	1	2	3	4	5	5m1
$\alpha(\%)$	-1.73	-0.53	1.53	2.32	3.77	5.50
	(-2.56)	(-0.69)	(2.37)	(3.17)	(3.67)	(4.15)
β_{MKT}	1.09	1.05	1.00	0.95	0.94	-0.15
	(64.87)	(45.73)	(64.52)	(51.42)	(34.71)	(-4.50)
β_{SMB}	-0.00	0.08	-0.00	-0.13	-0.05	-0.05
	(-0.07)	(2.15)	(-0.04)	(-6.74)	(-1.71)	(-1.22)
β_{HML}	0.02	-0.14	-0.06	-0.03	0.05	0.03
	(0.64)	(-3.72)	(-1.90)	(-0.82)	(1.11)	(0.47)
$R^2(\%)$	94.65	93.40	94.10	91.97	87.14	10.76
$\alpha(\%)$	-1.09	0.57	1.35	1.77	2.83	3.92
	(-1.55)	(0.66)	(2.07)	(2.37)	(2.72)	(2.96)
β_{MKT}	1.08	1.04	1.00	0.96	0.96	-0.13
	(63.87)	(46.13)	(65.06)	(52.14)	(37.31)	(-4.09)
β_{SMB}	-0.00	0.08	-0.00	-0.13	-0.05	-0.04
	(-0.15)	(2.36)	(-0.02)	(-6.37)	(-1.53)	(-1.18)
β_{HML}	0.01	-0.16	-0.06	-0.02	0.07	0.06
	(0.22)	(-4.58)	(-1.76)	(-0.50)	(1.72)	(1.15)
β_{MOM}	-0.05	-0.09	0.01	0.04	0.07	0.12
	(-2.79)	(-3.49)	(0.67)	(1.98)	(2.69)	(3.42)
$R^2(\%)$	94.81	93.85	94.12	92.13	87.60	15.38

Table 4 shows asset pricing tests for 5 portfolios sorted on organization capital over assets (Compustat item at) relative to the industry. We classify firms into 17 industries, according to Fama and French (1997). SMB and HML refer to the Fama and French (1993) factors and MOM to the Carhart (1997) momentum factor, available from Kenneth French's website. Organization capital is defined as $O_{i,t} = (1 - \delta)\, O_{i,t-1} + SGA_{i,t}$, where SGA is Selling, General and Administrative Expenses (Compustat item xsga). We chose $\delta = 0.15$. In the portfolio sorts, we only include firms where $O_{i,t} > 0$. The sample period is January 1970 to December 2008. t-statistics, reported in parenthesis, are computed using the Newey-West estimator allowing for 1 lag of serial correlation in returns. All numbers are annualized by multiplying by 12.

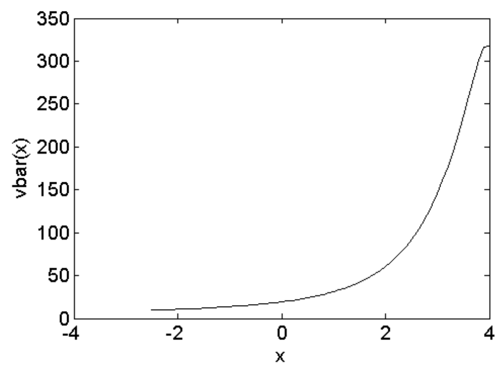
Table 5: Parameters

Parameter	r	c_o	λ	λ_θ	μ_θ	σ_θ	λ_x	κ_x	σ_x	κ_ε	σ_ε	c	$\sigma_{\mathcal{O}}$
value	0.04	3000	3.5	0.2	0.005	0.15	-0.85	0.1	0.2	0.35	0.75	5	0.2

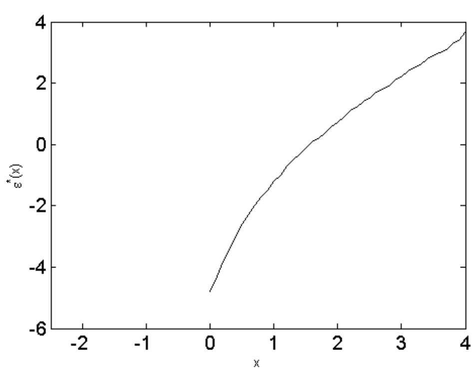
Figure 1: Solution



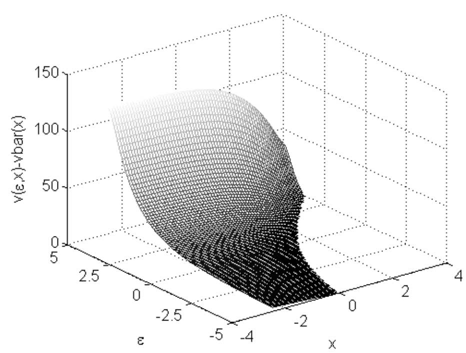
$v(\varepsilon, x)$



$\bar{v}(x)$



$\varepsilon^*(x)$



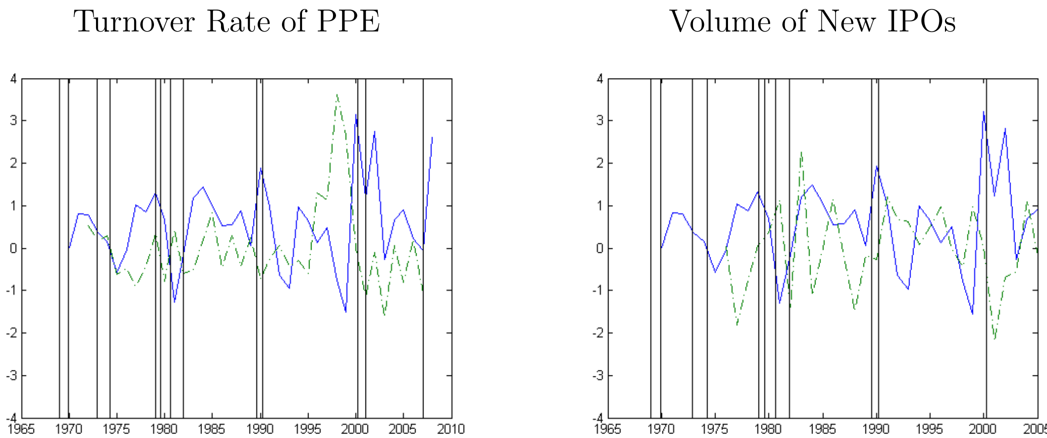
$v(\varepsilon, x) - \bar{v}(x)$

Table 6: Model: 5 portfolios sorted on $\mathcal{O}/A$

	Lo	2	3	4	Hi	Hi-Lo
Organization Capital to Physical Capital	0.038	0.131	0.315	0.762	2.798	
V_{org}/V	0.021	0.062	0.131	0.262	0.571	
Degree of Operating Leverage	0.996	1.008	1.033	1.174	1.606	
$\mu(\%)$	4.32	4.68	5.25	6.28	9.34	4.95
t	1.94	2.10	2.33	2.72	3.47	3.62
$\sigma(\%)$	15.70	15.78	15.96	16.40	19.12	9.76
$\alpha(\%)$	-1.87	-1.63	-1.22	-0.43	1.64	3.52
t	-2.89	-2.76	-2.46	-1.17	2.71	2.96
β^{MKT}	0.88	0.90	0.92	0.95	1.08	0.20
t	20.72	22.79	27.54	39.00	26.81	2.59
$R^2(\%)$	90.01	91.71	94.13	97.01	94.05	12.76
$\alpha(\%)$	-0.06	0.01	0.12	0.34	-0.06	
t	-0.32	0.08	0.65	1.20	-0.32	
β^{MKT}	0.99	0.99	0.99	1.00	0.99	
t	81.64	84.10	77.88	57.34	81.64	
β^{5m1}	-0.51	-0.46	-0.38	-0.22	0.49	
t	-22.44	-21.56	-16.00	-6.73	20.89	
$R^2(\%)$	99.25	99.31	99.23	98.61	99.51	

Table **??** shows moments and characteristics of portfolios sorted on the ratio of organization capital to physical capital for simulated data. Every year, we sort firms into 5 quintiles, based on the ratio of $\mathcal{O}$ to K. We use only the second half of the sample, to mitigate the impact of initial values. We use medians as measures of portfolio characteristics. We estimate operating leverage by $DOL_{i,t} = \Delta \log(Y - w - c_o \lambda^{-1} i^{\lambda} \mathcal{O}\theta)/\Delta \log Y$, i.e. the ratio of the percentage change in profits to the percentage change in output. We simulate 2000 firms for a length of 100 years, and report medians across 2000 simulations.

Figure 2: High minus Low OC stock returns versus Reallocation



The left panel of Figure 2 plots the returns of the high minus low organization capital portfolios (solid line) versus innovations in the turnover rate of Property Plant and Equipment (dotted line), from Eisfeldt and Rampini (2006). The turnover is defined as aggregate sales of PPE in Compustat data relative to aggregate PPE. Innovations are obtained from an AR(1) model. The correlation between the two series is -31.8%, with a t-statistic of -1.96. Dotted vertical lines plot NBER recession dates. The right panel of Figure 2 plots the returns of the high minus low organization capital portfolios (solid line) versus innovations number of new IPOs (dotted line), from Ibbotson, Sindelar and Ritter (1994). The number of IPOs excludes penny stocks, units and closed-end funds. Innovations are obtained from an AR(1) model. The correlation between the two series is -26.1%, with a t-statistic of -2.09. Dotted vertical lines plot NBER recession dates.

Table 7: Data: Investment in Organizational Capital

i_t^{oc}	(1)	(2)	(3)	(4)	(5)	(6)
$\tilde{R}^x_{t-1}$	0.0337	0.0515	0.0369	0.0234	0.0267	0.0372
	(2.85)	(3.88)	(4.33)	(5.19)	(5.95)	(3.05)
Δy_{it}			0.1945	0.0858	0.0810	0.1066
			(14.58)	(6.74)	(6.27)	(10.36)
CF_{t-1}/A_{t-2}			0.0265	0.0418	0.0370	0.0212
			(2.77)	(4.69)	(4.03)	(1.95)
$\ln Q_{t-1}$			0.2018	0.1449	0.1565	0.2137
			(16.60)	(17.21)	(17.75)	(12.50)
$\ln E_{t-1}/A_{t-1}$			0.0380	0.0385	0.0263	0.0487
			(4.70)	(6.08)	(4.43)	(4.83)
$\ln \mathcal{O}_{t-1}/A_{t-1}$			-0.0061	0.0042	-0.0427	-0.2110
			(-0.57)	(0.59)	(-5.19)	(-8.60)
i^{oc}_{t-1}				0.4068	0.3815	
				(14.32)	(13.68)	
Observations	88860	88860	88860	88860	88860	88860
R^2	0.001	0.329	0.105	0.252	0.265	0.386
Fixed Effects	-	F	-	-	I	F

Table 7 shows estimates of a regression of investment rates on organizational capital on firm characteristics. The variables are defined as follows $\mathcal{O}$: Organizational Capital, constructed as $\mathcal{O}_{i,t} = (1-\delta)\,\mathcal{O}_{i,t-1} + SGA_{i,t}$, where SGA is Selling, General and Administrative Expenses (Compustat item xsga), $i_t^{oc} = SGA_t/O_{t-1}$, y: log sales (Compustat item sale) E: Book Equity (Compustat item ceq), A: Book Assets (Compustat item at), CF: Cashflows (Compustat item dp + item ib), Q: December market capitalization from CRSP over Book Assets plus Organizational Capital. $\tilde{R}^x_{t-1} = \sum_{l=1}^{4} R^1_{t-l} - R^5_{t-l}$ refers to minus the accumulated log returns on the $5-1$ portfolio, i.e. the portfolio long high and short low organization capital firms. The sample period is January 1970 to December 2007. For the industry fixed effects we use the 17 industry classification of Fama and French (1997). Standard errors are robust to heteroscedasticity and clustered by firm and year. All data are standardized to have mean zero and unit variance.

Table 8: Model: Investment in Organizational Capital

	(1)	(2)	(3)	(4)	(5)
$\tilde{R}^x_{t-1}$	0.0852	0.0852	0.0936	0.0805	0.0944
	(2.26)	(2.24)	(2.50)	(2.61)	(2.48)
Δy_{it}			0.1059	0.0572	0.1013
			(6.45)	(4.09)	(5.85)
CF_{t-1}/A_{t-2}			0.0643	0.0443	0.0500
			(3.31)	(3.22)	(2.89)
$\ln Q_{t-1}$			0.0689	0.0678	0.0855
			(2.08)	(2.48)	(2.10)
$\mathcal{O}_{t-1}/A_{t-1}$			-0.0172	-0.0160	-0.0893
			(-1.46)	(-1.54)	(-3.29)
i^{oc}_{t-1}				0.2108	
				(19.83)	
Observations	100000	100000	100000	100000	100000
R^2	0.008	0.051	0.044	0.087	0.088
Fixed Effects	-	F	-	-	F

Table 8 shows median estimates across 2000 simulations of a regression of investment rates on organizational capital on firm characteristics. The variables are defined as follows $\mathcal{O}$: Organizational Capital, i^{oc}_t, investment in organization capital, $y = \ln Y$: log output, K: Book Assets, CF: Cashflows, $y - w$, Q: V over $K + \mathcal{O}$. Every year, we sort firms into 5 quintiles, based on the ratio of $\mathcal{O}$ to K. $\tilde{R}^x_{t-1} = \sum_{l=1}^{4} R^2_{t-l} - R^5_{t-l}$ refers to minus the accumulated log returns on the $5 - 1$ portfolio, i.e. the portfolio long high and short low organization capital firms. We simulate 2000 firms for a length of 100 years. We use only the second half of the sample, to mitigate the impact of initial values. Standard errors are robust to heteroscedasticity and clustered by firm and year. All data are standardized to have mean zero and unit variance.

Appendix

Examples of Organization Capital from 10-K filings

1. High Organization Capital Firms

   - INTELLICORP INC, technology services firm, FY2000 10-K filings:
     "We are dependent upon a limited number of key management, technical and sales personnel, the loss of whom would have an adverse effect on our business, financial condition and results of operations. Because of the complexity of the technology of our services and products, we may only have a single employee with appropriate expertise. The loss of such an employee could have the effect of slowing down or stopping a customer consulting engagement or the development of a product until we are able to find a replacement with the requisite expertise."
   - CASTLE A M & CO, metals service center, FY2001 10-K filings:
     "A prime example is our WMS (Warehouse Management System), which is now 95% operational at our Chicago location. In addition to significantly improving customer service levels, this electronic bar coded system greatly reduces our costs to store, locate, cut and ship a wide variety of metal sizes and shapes, and maximizes efficiency in our order picking process."
   - VIRCO MANUFACTURING CO, furniture manuf., FY1996 10-K filings:
     " The educational product line is marketed through what we believe to be the largest direct sales force in the educational furniture industry in addition to a variety of educational distributorships. The sales force calls directly upon school business officials, which can include purchasing departments or individual school principals where site based management is practiced. Our direct sales force is considered to be an important competitive advantage over competitors who rely primarily upon dealer networks for distribution of their products.
   - STRIDE RITE CORP, footwear, FY2005 10-K filings:
     "Our business operations are dependent on our logistical systems, which include our order management system and our computerized warehouse network. The logistical systems enable us to procure our footwear products from overseas manufacturers, transport it to our distribution facilities, store it and timely deliver it to our customers, in the correct sizes and styles. A disruption to the logistical systems could have a material adverse impact on our business."
   - COCA COLA CO, soft drinks manuf., FY1997 10-K filings:
     "Our continued success depends on recruiting, training and retaining people who can quickly identify and act on profitable business opportunities. This means maintaining and refining a corporate culture that encourages learning, innovation and value creation on a daily basis. The Coca-Cola Learning Consortium works with the management of our entire system to foster learning as a core capability. This group helps build the culture, systems and processes our people need to develop the knowledge and skills to take advantage of new opportunities."

2. Low Organization Capital Firms

- EXCEL SWITCHING CORP, telecommunications, FY1997 10-K filings:
  "The Company is also implementing additional financial and management procedures which the Company believes will address increasing demands on resources. However, the Company believes that further improvements in management and operational controls are needed, and will continue to be needed, to manage any future growth. Continued growth will also require the Company to hire more engineering, selling and marketing and administrative personnel, expand customer support capabilities, expand management information systems and improve its inventory management practices. The Company has at times experienced, and continues to experience, difficulty in recruiting qualified personnel."
- MACROCHEM CORP, pharmaceutical, FY1997 10-K filings:
  "Lack of marketing experience; dependence on third parties for marketing and distribution of products: The Company intends to market and distribute its proposed products through others pursuant to licensing, joint venture, or similar collaborative arrangements or distribution agreements. The Company has no sales force or marketing organization. If the Company directly markets and sells any of such products, it will, among other things, have to attract and retain qualified or experienced marketing and sales personnel. No assurance can be given that the Company will be able to attract and retain qualified or experienced marketing and sales personnel or that any efforts undertaken by such personnel will be successful."
- CEPHALON INC, biotechnology, FY2002 10-K filings:
  "In addition, we may be at a competitive marketing disadvantage against companies that have broader product lines and whose sales personnel are able to offer more complementary products than we can. Any failure to maintain our competitive position could adversely affect our business and results of operations. "
- GENZYME, biotechnology, FY1999 10-K filings:
  "Some of these competitors may have more extensive research and development, regulatory, manufacturing, production, and sales and marketing capabilities. We may be required to license technology from competitors in order to develop and commercialize some of our products and services, and it is uncertain whether these licenses will be available to us on acceptable terms or at all. "
- EXPEDIA, travel services, FY2002 10-K filings:
  "Currently, a majority of our transactions are processed through two GDS partners: Worldspan, L.P. and Pegasus Solutions, Inc. We rely on TRX, Inc. and PeopleSupport, Inc. to provide a significant portion of our telephone and e-mail customer support, as well as to print and deliver airline tickets as necessary. Any interruption in these third-party services or deterioration in their performance could impair the quality of our service. If our arrangement with any of these third parties is terminated, we may not find an alternate source of systems support on a timely basis or on commercially reasonable terms."

Numerical Solution

We solve the HJB Equation characterizing the solution using standard techniques. In the continuation region, the function $v(\varepsilon, x)$ satisfies the equation

$$0 = \max_i \left[\exp(\varepsilon) - c_o \lambda^{-1} i^{\lambda} - (r + \delta - \mu_Q - i)\, v - \kappa_\varepsilon\, \varepsilon\, v_\varepsilon + \frac{1}{2} \sigma_\varepsilon^2 v_{\varepsilon\varepsilon} - \kappa_x\, (x - \overline{x}) v_x + \frac{1}{2} \sigma_x^2\, v_{xx} \right]$$

solving for the optimal investment policy yields the following PDE

$$0 = \exp(\varepsilon) - c_o \lambda^{-1} i^{\lambda} - (r + \delta - \mu_Q - i)\, v - \kappa_\varepsilon\, \varepsilon\, v_\varepsilon + \frac{1}{2} \sigma_\varepsilon^2 v_{\varepsilon\varepsilon} - \kappa_x\, (x - \overline{x}) v_x + \frac{1}{2} \sigma_x^2\, v_{xx}$$

where

$$i = \left(\frac{v}{c_0} \right)^{\frac{1}{\lambda - 1}}$$

The continuation region is defined by $\varepsilon_{i,t} \geq \varepsilon^*(x_t)$, where $\varepsilon^*(x)$ solves

$$v(\varepsilon^*(x), x) = v(x, x) - c \equiv \overline{v}(x)$$

We discretize the state space, creating a 100×100 point grid for (ε, x) and v with $h_\varepsilon = \Delta\varepsilon, h_x = \Delta\, x$. Then the following approximations can be used

$$\begin{aligned}
v_\varepsilon(\varepsilon_n, x_m) &\approx \frac{v_{n+1,m} - v_{n-1,m}}{2h_\varepsilon} \\
v_{\varepsilon\varepsilon}(\varepsilon_n, x_m) &\approx \frac{v_{n+1,m} + v_{n-1,m} - v_{n,m}}{h^2} \\
v_x(\varepsilon_n, x_m) &\approx \frac{v_{n,m+1} - v_{n,m-1}}{2h_x} \\
v_{xx}(\varepsilon_n, x_m) &\approx \frac{v_{n,m+1} + v_{n,m-1} - v_{n,m}}{h^2}
\end{aligned}$$

We then approximate the PDE as

$$v_{n,m} = p_{n,m}^d v_{n-1,m} + p_{n,m}^u v_{n+1,m} + q_{n,m}^d v_{n,m-1} + q_{n,m}^u v_{n,m+1} + \left(\exp(\varepsilon_n) - c_o\, \lambda^{-1} i_{n,m}^{\lambda} \right) \Delta t_{n,m}$$

where

$$
\begin{aligned}
p^d_{n,m} &= \frac{\kappa_\varepsilon h_\varepsilon \, e_n + {\sigma_\varepsilon}^2}{2{h_\varepsilon}^2} \, \Delta t_{n,m} \\
p^u_{n,m} &= -\frac{\kappa_\varepsilon h_\varepsilon \, e_n - {\sigma_\varepsilon}^2}{2{h_\varepsilon}^2} \, \Delta t_{n,m} \\
q^d_{n,m} &= \frac{\kappa_x h_x (x - \overline{x}) + {\sigma_x}^2}{2{h_x}^2} \\
q^u_{n,m} &= -\frac{\kappa_x h_x (x - \overline{x}) - {\sigma_x}^2}{2{h_x}^2} \\
\Delta t_{n,m} &= \frac{{h_\varepsilon}^2 {h_x}^2}{{\sigma_\varepsilon}^2 {h_x}^2 + {\sigma_x}^2 {h_\varepsilon}^2 + (r + \delta - \mu_Q - i_{n,m}) \, {h_\varepsilon}^2 {h_x}^2}
\end{aligned}
$$

Note that care must be taken when choosing (h_ε, h_x) to ensure that the probabilities are non-negative at all points in the grid. Alternative differencing schemes that produce positive probabilities can also be used.

Using an initial guess for v, say v^j, we compute the optimal policy, and then we recursively iterate on v and the policy until convergence:

$$
\begin{aligned}
i^j_{n,m} &= \left(\frac{v^j_{n,m}}{c_o} \right)^{\frac{1}{\lambda - 1}} \\
\Delta t^j_{n,m} &= \frac{{h_\varepsilon}^2 {h_x}^2}{{\sigma_\varepsilon}^2 {h_x}^2 + {\sigma_x}^2 {h_\varepsilon}^2 + (r + \delta - \mu_Q - i^j_{n,m}) \, {h_\varepsilon}^2 {h_x}^2} \\
v^{j+1}_{n,m} &= \max \Big[v^j(\varepsilon = x_m, x_m) - c, \quad p^d_{n,m} v^j_{n-1,m} + p^u_{n,m} v^j_{n+1,m} + q^d_{n,m} v^j_{n,m-1} + q^u_{n,m} v^j_{n,m+1} \\
&\qquad + (\exp(\varepsilon_n) - c_o \, \lambda^{-1} {i^j_{n,m}}^{\lambda}) \Delta t^j_{n,m} \Big]
\end{aligned}
$$

We impose reflecting barriers on (ε, x) at the boundaries of the grid. This reduces to $v_{0,m} = v_{1,m}$, $v_{N,m} = v_{N-1,m}$, $v_{n,0} = v_{n,1}$, $v_{n,M} = v_{n,M-1}$ since there is no discounting at the boundary.