Q-Theory of Investment Revisited: Merton's *q*

HURSIT S. CELIL and MENGYANG CHI*

ABSTRACT

We utilize an option pricing framework to construct a proxy for market value of a firm's physical assets, which is then used to estimate the marginal value of an additional unit of capital. The proposed measure outperforms its alternatives by explaining more than 63% of investment dynamics during the period of 1985-2012. Other conventional determinants of investment such as a firm's cash holdings lose their explanatory power in a standard investment model. We confirm that the empirical underperformance of investment theory is subject to a measurement error problem in marginal q rather than capital market imperfections.

JEL classification: E22, E44, G31.

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Investment decisions are related to future prosperity. The association between them induces economic agents to primarily focus on maximizing a return on invested capital in excess of its cost. Since Tobin's (1969) seminal work first appeared in the literature, a significant amount of research has been devoted to understanding the investment choices of individuals. Specifically Tobin's argument relies on the idea that the rate of investment should be related to the benefit of such choices (i.e. market value of invested capital) with respect to their associated cost (i.e. replacement cost of invested capital). Related theoretical frameworks also have relied on this fundamental principle. For instance, Lucas and Prescott (1971) propose a dynamic investment model with convex adjustment cost to capture the dynamics of investment. Abel (1979) shows that the rate of investment, which is the pace of reaching optimal level of capital stock, is mainly driven by marginal value of investment. Hayashi (1982) equates marginal value of investment to its average value by assuming an investor is a price taker and both production and installment of capital are homogeneous.[1] Although marginal value of investment is not directly observable in data, one can test the predictions of underlying theory by constructing its corresponding proxy, $q^{average}$, under Hayashi's assumptions.

Empirical investigation of an investment model has failed to provide satisfactory subsequent results (e.g., Chirinko (1993), and Caballero, Engel, and Haltiwanger (1995)). Specifically $q^{average}$ was not powerful enough to explain a large proportion of investment dynamics and residuals in standard regression models appeared to be correlated with other omitted factors, i.e. investors' financial prospects (e.g., Hassett and Hubbard (1996), and Caballero (1999)). In this paper, we intend to circumvent these potential shortcomings of underlying

[1] Hayashi (1982) defines marginal value of investment as the ratio of market value of an additional unit of capital to its replacement cost, whereas average value of investment is defined as the market value of existing capital scaled by its replacement cost.

theory by providing an alternative approach to approximate the marginal value of investment.

In order to test the validity of the underlying theory of investment, we first adopt the structural framework of Black and Scholes (1973) and Merton (1974) for pricing options and obtain a proxy for market value of a firm's assets in place. The model treats a firm's equity as a call option which is written on its underlying asset with a strike price of its face value of outstanding debt. Since the model is designed to account for the firm's financial prosperity through its expected default probability, it provides a better measure of its market value than the conventional measures that are used in standard finance literature, such as the sum of book value of a firm's debt and market value of its outstanding equity as a proxy for its market value. Derived value of a firm's assets is then used to construct a new $q^{average}$ measure, denoted as q^{merton}. Given data availability, we test the implementation of q-theory of investment and analyze the performance of q^{merton} against its alternatives, such as $q^{classic}$ by Hall (2001) and q^{bond} by Philippon (2009), in explaining investment dynamics during the time period from 1985 to 2012.

According to our findings, q^{merton} accounts for approximately 66% (64%) variation in aggregate level of physical asset investments in the U.S. economy during 1985-2007 (1985-2012). Several key components of other measures that are documented to be significantly correlated with investment level, such as idiosyncratic volatility, real discount factor, relative corporate bond prices and leverage, are found to lose their explanatory power at conventional significance levels.[2] In addition, the aggregate level of cash flow enters the investment regres-

[2] "In the short run, q^{bond} depends mostly on the relative price component. Year-to-year changes in $(\phi + r_t^{10})/(\phi + y_t^{Baa})$ account for 85% of the year-to-year changes in q^{bond}. In the long run, leverage, and especially, idiosyncratic volatility are also important" (see, for example, Philippon (2009), p. 1032). Although empirical evidence on the relationship between some of these variables and investment in physical asset is not conclusive enough, we take such an underlying association as given by the existing literature.

sion as an insignificant factor once we control for q^{merton} and use an alternative investment measure generated from the same sample.[3] In contrast to the findings of prior literature, we observe that idiosyncratic volatility and real discount factor are negatively associated with the aggregate level of investment at the 5% significance level during the time period after 1985. Our findings are also economically meaningful. During 1985-2007, q^{merton} increases the investment-q sensitivity by about 31% and 60% comparing to $q^{classic}$ and q^{bond}. When we extend the time to 2012 and use an aggregate investment measure from Compustat-CRSP sample, a one standard deviation increase in $q^{classic}$ and q^{merton} increase the investment rate by 0.540% and 0.809% per quarter respectively.[4] These results translate into 2.18% and 3.28% annual increase in investment rate at the aggregate level.[5]

We believe the power of q^{merton} over the alternative factors in explaining investment comes from its ability to capture the difference between market value of a firm's debt and its book value. In fact, the results at the firm level analyses indicate that almost 71% of the explanatory power of q^{merton} comes from the sample of firms that have significant deviations between book value and market value of debt. On average, these firms are either risky in terms of their credit ratings or having high levels of debt in their capital structures. These results are also in agreement with the findings in bond pricing literature, which often tests the power of different structural models in explaining yield spreads (e.g., Jones, Mason, and

[3] q^{merton} is constructed by using publicly traded U.S. firms' accounting and market information, and hence does not reflect the prospects of private firms directly. Unfortunately, this is the caveat of using publicly available data from S&P's Compustat and CRSP merged data sample which reflects only the information about public firms. However, the effect of investment dynamics of private firms at the aggregate level is documented to be a relatively small portion of investment dynamics at macro level, i.e. correlation between investment measures of alternative investment measures are close to 74%.

[4] In Philippon (2009), an increase in q^{bond} ($q^{classic}$) by a one standard deviation would lead to an increase in investment rate of 0.761%(0.309%) per quarter.

[5] According to World Development Indicators by the World Bank annual GDP per capita growth of the USA is approximately around 1.66% (2.06%) on average during period of 1985-2012 (1985-2007).

Rosenfeld (1984), and Eom, Helwege, and Huang (2004)).[6]

We also observe that q^{merton} performs better in explaining investment rates when we restrict our sample to firms that rely more heavily on tangible capital. Although q^{merton}'s explanatory power drops by 20% when low tangibility firms are included back into the sample, its overall performance is still better than its alternatives. One potential explanation is that these firms rely more heavily on other type of inputs, i.e. intellectual properties rather than physical assets, to produce final outputs (e.g., Hall (2001), and Peters and Taylor (2016)). However, in order to test the implications of q-theory of investment and directly reconcile our observations with the concerns raised by prior literature, we do not deviate away from underlying theoretical structure. In this regard our findings are empirically robust for alternative specifications such as an extension of time span to post financial-crisis period or the construction of aggregate measures by using a different sample of firms.

In specific, research design in this paper is in line with academic work that is motivated to address the potential failures of the underlying investment theory due to its corresponding assumptions. It is possible that some firms may not necessarily be price-takers or do not satisfy constant returns to scale assumption on production functions. For instance, as in Cooper and Ejarque (2003), Alti (2003), and Abel and Eberly (2012) technological frictions may drive a wedge between the actual measures and their empirical proxies. It is also possible that some firms may not be facing convex adjustment cost functions (e.g., Dixit and Pindyck (1994), Caballero and Engel (1999), and Cooper and Haltiwanger (2006)). Alternatively financial frictions may lead to omitted variables problem in investment regressions, since

[6] According to Jones et al. (1984) and Eom et al. (2004), Merton's (1974) bond pricing model suffers from over-predicting bond prices but other structural models tend to severely overstating the riskiness of firms. The estimation errors in Merton's (1974) bond prices are higher for non-investment grade firms. However, the model still works better for low-grade bonds since it has a greater incremental power to explain riskier bond prices. Due to the related arguments, in our valuation approach we adopt Merton's (1974) original framework and do not relax any of its underlying assumptions.

such frictions of some other firms may play a role in investment decisions (e.g., Bernanke and Gertler (1989), Fazzari, Hubbard, and Petersen (2000), Hennesy, Levy and Whited (2007), Bustamante(2011), and Bolton, Chen and Wang (2011)). Finally, aggregation biases in some of the main variables may empirically generate unsatisfactory results.

However, Hall (2003) provides evidence of firms' price-taking behaviors and constant returns to scale of production functions. A convex adjustment cost function may still be a restrictive assumption at the firm level, but its impact is still inconclusive at the aggregate level (e.g., Thomas (2002), Hall (2004), and Bachmann, Caballero, and Engel (2006)). Hall (2004) shows that aggregation bias is not the main reason behind the failure of existing models. Furthermore Gilchrist and Himmelberg (1995), and Abel (1986) apply vector autoregression models (VAR) rather than conventional methods to construct $q^{average}$. Such measures can potentially capture the investment-to-cash flow sensitivities. Correspondingly Gomes (2001) documents that financial constraints do not matter and if there are no measurement error problems then $q^{average}$ should be a main factor in explaining economic agents' investment choices. Cummins, Hassett, and Oliner (2006) use analyst forecast to estimate $q^{average}$, which can also potentially offset the valuation errors in equity markets. Erickson and Whited (2000, 2006) propose a generalized method of moments (GMM) estimator to cure some of the problems that one can observe in data.[7] Therefore we believe a common consensus at the empirical strand of investment literature is that the measurement problems in some key components of investment models might be the reason behind unsatisfactory empirical results of q-theory of investment, and in this paper we hope to provide a way to minimize them to an extent.

[7] In untabulated results, we also analyze the magnitude of measurement errors in q^{merton} within the context of Erickson and Whited (2000, 2006, 2010) at the firm level. We find that q^{merton} is still subject to some level of measurement error at the disaggregated level, which is relatively smaller than the measurement errors in its alternatives.

In a similar context, our approach is more in line with Philippon (2009), who proposes an alternative proxy, q^{bond}, based on the information in bond markets. The q^{bond} measure is motivated to capture the discrepancy between the mispricing of bond and equity markets. Although relative performance of q^{bond} against $q^{classic}$ measure decreases significantly after the 1980s, q^{bond} manages to outperform $q^{classic}$ in explaining the investment rate between 1953-2007.[8] The empirical power of q^{bond} mainly comes from four of its underlying factors: real interest rate, firm's leverage, idiosyncratic volatility of a firm's equity, and relative price of corporate to treasury bonds. Although our paper deviates from Philippon (2009) in many respects, perhaps it is important to underline that we are not relying on any extent of mispricing arguments in capital markets.

We believe our paper contributes to existing literature in several ways. Under the assumptions of q-theory of investment, q^{merton} is an economically and statistically significant factor in explaining aggregate level of fixed asset investment in the U.S. economy. Once the measurement errors in $q^{marginal}$ proxy is alleviated, it is possible to test the true underlying relationship between investment choices and their value to an economic agent within the classical empirical framework. Our methodology is intended to provide an alternative measure to obtain market value of debt as a part of market value of a firm's assets in this context. Although there exists a variety of bond pricing models, to the best of our knowledge, there is no common consensus on how one structural model outperforms and is superior to the other in explaining bond prices. In fact, nearly all pricing frameworks suffer from a mispricing problem one way or another, hence it is still common to use Merton's (1974) model as a benchmark in related studies.[9]

[8] R^2 in Philippon (2009, Table III) q^{bond} ($q^{classic}$) is 57% (10%).

[9] Geske (1977), Longstaff and Schwartz (1995), Collin-Dufresne, Goldstein, and Martin (2001) and many other related work relax the underlying assumption of Merton's (1974) framework and propose alternative ways to value corporate debt obligations. However, these models also suffer from over-predicting and under-

The main focus in this paper is to mitigate the measurement error problem in standard investment regression models, while the adopted methodology can be potentially extended and applied to various fields in financial economics. For instance it can be utilized to estimate a company's future growth prospects by assessing how much return it can generate for its shareholders by the amount of capital it invests today in its physical assets, which is one of the key determinants of value creation. Such advantage of Merton's (1974) framework is also recognized by many academicians and practitioners in assessing the credit worthiness of an economic entity, i.e. Moody's, Morningstar, and Standard & Poor's calculate the risk profile of a firm with their modified credit rating models based on Merton's (1974) original framework. In short, our results complement the existing view, which argues that in order to test the prediction of underlying theory, additional methodologies are necessary, if not sufficient, in providing better empirical proxies. Therefore, it is crucial to realize the importance of using more accurate measurement in empirical studies when identifying the pros and cons of underlying theoretical models.

The remainder of the paper is organized as follows. Section I explains the research design in our paper. Data sample and variable constructions are presented in Section II. Empirical findings are provided in Section III. Robustness of the results are tested in Section IV. Economic interpretation of our findings are presented in Section V. Section VI concludes the paper. Finally, details of Merton's option pricing framework and supplementary information on sample characteristics are provided in the Appendixes A & B.

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predicting firm's default risk that belongs to different asset classes, i.e. investment vs. non-investment grade firms.

I. Research Design

A. *Standard Investment Model*

We adopt a standard dynamic investment model as in Erickson and Whited (2000, 2010) to obtain our empirical regression framework. Risk-neutral managers choose investment to maximize firm value which is a function of invested capital subject to the capital accumulation process. Hence, the firm solves the following optimization problem:

$$V_{A,t} = \max_{I} E\Bigg[\sum_{j=0}^{\infty}\Bigg(\prod_{s=1}^{j} b_{t+s}\Bigg)[\pi(K_{t+j}, \zeta_{t+j}) - \psi(I_{t+j}, K_{t+j}, v_{t+j}) - I_{t+j}]\Bigg|\Omega_t\Bigg], \tag{1}$$

$$s.t. \quad K_{t+1} = (1-\delta)K_t + I_t \tag{2}$$

where $V_{A,t}$ denotes a firm's value at time t, E is the expectation operator; Ω_t is the information set obtained by the firm's manager at time t; b_t is time t's discount factor; K_t is the capital stock at the beginning of time t; I_t is the manager's investment decisions; $\pi(K_t, \zeta_t)$ is the firm's profit function with $\pi_K \geq 0$; ζ_t is the shock to profitability; and δ is the depreciation rate of capital.

As in Erickson and Whited (2000) and Alti (2003), we assume a convex capital stock adjustment cost has the following form,

$$\psi(I_t, K_t, v_t) = \frac{a}{2}(\frac{I_t}{K_t} - \delta + v_t)^2 K_t \tag{3}$$

which is linearly homogenous in I_t and K_t. $a > 0$ is the cost parameter and the adjustment function satisfies $\psi_I \geq 0, \psi_K \leq 0, \psi_{II} \geq 0$, and $\psi_{KK} \geq 0$. The exogenous shock to the adjustment cost is denoted as v_t.

First order condition of the maximization problem yields,

$$1 + \psi_I(I_t, K_t, v_t) = q_t, \tag{4}$$

where

$$\begin{aligned} q_t =& E\Bigg[\sum_{j=1}^{\infty}\left(\prod_{s=1}^{j} b_{t+s}\right)(1-\delta)^{j-1}[\pi_K(K_{t+j}, \zeta_{t+j}) \\ &- \psi_K(I_{t+j}, K_{t+j}, v_{t+j})]\Bigg|\Omega_t\Bigg]. \end{aligned} \tag{5}$$

The left hand side of equation (4) is marginal cost of additional unit of investment, whereas the right hand side of (5) is marginal benefit of the same unit of investment. By the price of unity assumption, q_t is known as $q^{marginal}$ in standard investment equation, and it measures the marginal value and marginal cost of investment. However, a major challenge in such empirical framework is that $q^{marginal}$ is not readily observable and it needs to be estimated.

In this regard it is traditional in the literature to measure a firm's market value by adding market value of the firm's equity and book value of its liabilities, which we argue as a potential source of measurement error in variables in standard investment equations. Hence, we propose a new measure based on Merton's (1974) option pricing model.[10] Differentiating equation (3) with respect to I_t and plug into (4) will provide a standard investment regression model,

$$y_t = \alpha + \beta q_t + v_t, \tag{6}$$

where $y_t = \frac{I_t}{K_t}$, $\alpha = \delta - \frac{1}{a}$, and $\beta = \frac{1}{a}$.[11] Equation (6) provides an empirical setting to

[10] We explain the construction of our measure more in detail in the following sections and in Appendix A.

[11] We use a regression equation model (6) to analyze the association of q with investment at the aggregate level, which is obtained by aggregating all the corresponding components.

test the implications of q-theory of investment, which suggests an investment rate should be related to q, if to anything.

B. *Market Value of Firm's Assets*

In this section we explain the methodology of obtaining firms' value by using Merton's (1974) option pricing model. A more detailed derivation and proofs are provided in Appendix A. At time t, suppose the firm has a book value of liability L_t with time to maturity T that pays zero coupons. The firm's value at the maturity is $V_{A,t+T}$. Hence, the probability of default will be the probability that $V_{A,t+T}$ is less than L_t.

Under Merton's framework, at any time t, the value of the firm $V_{A,t}$ follows geometric Brownian motion:

$$dV_{A,t} = \mu_A V_{A,t} dt + \sigma_A V_{A,t} dW_t \tag{7}$$

where W_t is a standard Wiener process. $dW_t = \varepsilon_t \sqrt{dt}$, $\varepsilon_t \sim N(0,1)$.

As in Bharath and Shumway (2008), Black and Scholes's (1973) and Merton's (1974) option pricing framework yield two equations, one expresses firms' equity value as a function of firms' total market value, the other relates firms' equity volatilities to asset volatilities. The following shows these two relations:

$$\mathrm{V}_{E,t} = \mathrm{V}_{A,t}\mathrm{N}(\mathrm{d}_1) - \mathrm{L}_t e^{-rT}\mathrm{N}(\mathrm{d}_2) \tag{8}$$

$$\sigma_E = \left(\frac{V_{A,t}}{V_{E,t}}\right) N(d_1)\sigma_A. \tag{9}$$

where $V_{E,t}$ denotes firms' equity value. σ_E and σ_A denotes firms' equity volatility and asset volatility respectively. $N(.)$ is cumulative density function of standard normal distribution,

$d_1 = \frac{\ln(\frac{V_{A,t}}{L_t})+(r+\frac{1}{2}\sigma_A^2)T}{\sigma_A\sqrt{T}}$, $d_2 = d_1 - \sigma_A\sqrt{T}$, and r is instantaneous risk-free rate.

Therefore, firm value $V_{A,t}$, and asset volatility σ_A can be obtained by solving (8) and (9) iteratively. In the next section we provide more information on the key parameter estimates that we use to obtain corresponding measures for calibrating our model.

II. Data Sample & Variable Construction

The data sample consists of non-financial and non-utility U.S. firms in the merged Compustat Quarterly files and CRSP dataset from 1985 to 2012. In certain parts of our analysis time periods are limited to 2007 when comparing the empirical performance of our q measure with its alternatives given data availability.[12] One of the main reasons that we focus on a data sample that starts from 1985 is because of the significant differences in the number of firms presented in Compustat Annual and Quarterly files, which are more pronounced in time periods before 1980s. By imposing this filter we want to capture as much information as possible without adding too many assumptions in constructing main variables in quarterly frequencies.[13] In addition, in later sections we investigate the source of the explanatory power of q^{merton} in explaining investment level dynamics by using firm level information, i.e. the S&P long-term bond rating, which is only available to us to a significant extent after 1984.

[12] If firms in quarterly Compustat have missing information, we fill in the gap with information from annual Compustat files. For missing stock variable we use the nearest available information from its history up to one year. For missing flow variable, we assume that the last available non-missing information is not altered and is equally distributed through time until the new information becomes public.

[13] In the Compustat Annual file there were approximately 4,200 firms in late 1970s, whereas only 2,700 of these firms appear in the Compustat Quarterly file due to the reporting requirements.

A. *Option Pricing Model Parameters*

We derive a firm's asset value and its volatility by using Merton's (1974) option pricing framework which is explained in Section I.B and Appendix A. Firm's idiosyncratic volatility is measured by the firm's stock volatility over the calendar year, $\sigma_{E,t}$. We calculate the market value of the firm's equity by multiplying the firm's equity price with its outstanding shares, $V_{E,t}$. The risk free rate is instantaneous yield on a one year Treasury bond and denoted as r, which is obtained from the Federal Reserve of Economic and Research Data (FRED). As in Bharath and Shumway (2008), face value of debt is assumed to be equal to the sum of a firm's debt in its current liabilities and half of its longterm debt, L_t.

Market value of the firm's asset, $V_{A,t}$ and its volatility, $\sigma_{A,t}$, is obtained by solving equation (8) and equation (9) simultaneously and iteratively, where $V_{E,t}$, $\sigma_{E,t}$, r, and L_t are used as initial parameter estimates. Specifically, $\sigma_{E,t}$ is used as an initial input value for the estimation of $\sigma_{A,t}$ in equation (9). Using the Merton's formula for each trading day of the past 12 months, we compute a firm's asset value, $V_{A,t}$ by using $V_{E,t}$ as the market value of equity of that day. Afterwards we compute $\sigma_{A,t}$ of $V_{A,t}$, which is then used as inputs of $\sigma_{A,t}$ in equation (8) for the next iteration.

This procedure is repeated until the values of $\sigma_{A,t}$ from two consecutive iterations converge in values at a tolerance level of 0.001.[14] Once the value of $\sigma_{A,t}$ is obtained, we use it to obtain $V_{A,t}$ through equation (8).[15] This iteration process is repeated at the end of every month,

[14]For some firms, it takes only a few iterations for $\sigma_{A,t}$ to converge to a certain value, as is also the case in prior literature (e.g., Vassalou and Xing (2004)).

[15]Variation of this methodology is also used in the finance industry to estimate a firm's financial health and stability, i.e. firm's likelihood to default on its debt obligations. Moody's KMV methodology uses this approach to estimate credit worthiness of an economic entity (e.g., Vassalou and Xing (2004), and Bharath and Shumway (2008)). Specifically, Moody's KMV adopts Bayesian adjustments for the size of a country, an industry, and a firm to calculate its corresponding asset volatility. In addition, KMV also accounts for convertibles and preferred stocks in the firm's capital structure.

resulting in the estimation of monthly values of $\sigma_{A,t}$ and $V_{A,t}$. Time to maturity, T is always assumed to be 12 months in equation (8).

B. *Investment, Capital Stock & $q^{average}$ Measures*

We obtain $q^{classic}$, q^{bond}, aggregate level of capital stock and investment measures by following Hall (2001) and Philippon (2009), respectively.[16] Hall's (2001) sample spans the time period from 1946 to 1999. On the other hand, Philippon (2009) covers data from 1953 to 2007.[17] We use flow of funds data to construct $q^{classic}$, which is the ratio of the value of the firm adjusted for book value of its inventories to replacement cost of capital net of depreciation. Investment measure consists of non-residential fixed investment, scaled by current stock of capital at the beginning of the calendar quarter. In order to check the robustness of our findings, we also construct an aggregate level of investment by using the information available to us in Compustat and CRSP merged database (Hereafter, CRSP-Compustat universe).

In order to construct q^{merton} we first calculate the market value of each firm's assets in our sample by using the iterative process that is explained in Section I.B. Similar to other $q^{average}$ measures, market value of assets needs to be adjusted with the value of inventories, which is then scaled by the replacement cost of capital. Thus, we calculate aggregate measure as the sum of all firms' asset value less inventories divided by total replacement cost of physical capital net of depreciation.

[16]We thank Robert E. Hall, and Thomas Philippon for making their data available to us. More details on the construction of $q^{classic}$, q^{bond}, and investment variables used in our paper can be found in their corresponding papers.

[17]In order to extend the sample data to 2012 and check the robustness of our results, we closely follow the guideline provided by Hall (2001).

C. Control Variables

In order to check the explanatory power of q^{merton} against some other variables that appeared to be significant in prior literature, such as book leverage, idiosyncratic volatility, expected inflation, real discount factor, and relative price of corporate bonds, we closely follow Philippon (2009) and Hall (2001, 2004) to construct our control variables. Moody's BAA rated corporate bond prices and treasury yields are obtained from FRED. Expected inflation comes from the Livingston survey. Idiosyncratic volatility is calculated by the methodology of Goyal and Santa-Clara (2003) as the six months moving average volatility of daily stock returns. We calculate the aggregate level of book leverage, as the book value of corporate bonds divided by replacement cost of capital net of depreciation. Finally, we measure the aggregate level of cash flow by taking the sum of income before extraordinary items and depreciation and amortization divided by the sum of capital stock net of depreciation as in prior studies (e.g., Erickson and Whited (2000)).

D. Sample Filtration

Following prior literature, we delete observations if the firm has missing data on operating income, capital expenditure, net property, plant and equipment, and asset value (e.g., Erickson and Whited (2000, 2006), and Philippon (2009)). We require that each firm has non-negative face value of debt in current liabilities as well as long term debt. We exclude LIFO firms from this sample.[18] We also require firms to have non-negative replacement cost of capital, which is measured by the firm's net property, plant and equipment. Second,

[18]In order to have consistency in our inventory measure, we use first-in-first-out (FIFO) principle in our sample. Although this requirement caused us to loose 16% of the observations from the initial CRSP-Compustat universe, we alleviate the possibility that recalculating inventories could induce additional measurement errors in the quarterly file.

we delete observations if a firm's net property, plant and equipment is less than 20% of its total assets. The main reason for this filter is to obtain a sample of firms with a significant portion of its assets consisting of tangible capital, since it is likely that an excluded firm's market value of assets reflect mainly non-physical capital investments.[19] Appendix B reports the average value of total asset components of firms that are included and excluded in our sample. Finally, we select firms where Merton's model generate deviations between market value of the firm's debt and its book value. This criterion enables us to investigate the pure impact of market valuation and mitigate the chances when Merton's model might not work well for certain firms. Further, we relax these restrictions and check the robustness of our results in Section V.

III. Results

We provide descriptive statistics of our sample from 1985 to 2007 in Panel A of Table I. Sample mean (standard deviation) value of I/K_H and I/K_P are 3.55% (0.37%), and 10.44% (0.91%), respectively. We believe the main reason for the discrepancy between the distribution of these two measures of investment is because of the assumption on the depreciation rate of capital stock.[20] Due to a similar reason, we observe the distributions of alternative q-measures are significantly different from each other. The sample mean of $q^{classic}\_H$ and $q^{classic}\_P$ are 1.54 and 2.63, respectively. In Panel A, we also provide the distribution of an alternative investment measure that is constructed from the sample of CRSP-Compustat universe, I/K_C, which is subject to our sample selection criteria that

[19] We define firm's tangibility as the ratio of firm's capital stock net of depreciation to its total asset.

[20] Although Philippon (2009) does not specifically state the depreciation rate of physical capital that he uses to construct his measures, Hall (2001) takes this rate as 10% per year. We believe this is one of the reasons why we observe the differences in related measures.

are explained in Section II.D. Although the range of I/K_C is similar to I/K_H, we observe that it is relatively more volatile than alternative investment measures.

The mean of q^{merton} is 1.63, which is slightly higher than $q^{classic}\_H$ and q^{bond}. However, it is more (less) volatile than q^{bond} ($q^{classic}\_H$). Mean values of the real risk free rate, book leverage, idiosyncratic volatility, and inflation rate during the period of 1985-2007 are also provided in this table, which are 3.49%, 56.77%, 20.61% and 3.12%, respectively. Time series distributions of these values are in close range to the reported values in prior literature, such as in Hall (2001, 2003).

[Place Table I about here]

In order to ensure that our findings in later sections are not driven by time span, we extend our sample to post-financial crisis period. Tabulated summary statistics of the key variables in the extended sample are presented in Panel B of Table I. We observe that the inclusion of more recent years does not alter the distribution of our sample significantly.[21] Cash flow, which is often used to analyze the investment-to-cash flow sensitivity in the related literature, is on average 2.92% with a 1.94% standard deviation. We should note that there are some time periods in our data, specifically around financial crisis, where this aggregate measure reaches negative levels.

[Figure 1 about here]

In Figure 1, we provide time series distributions of alternative investment variables. We observe that investment in physical assets at the aggregate level spikes up significantly after the first Gulf War in all three measures. Alternative measures of investment are co-cyclical

[21] Since Philippon's (2009) measures are not available to us after 2007, we exclude his q-measure along with its components from Panel B of Table I.

with each other throughout our time span. There is a significant reduction in investment following the Dot.com crash. Right after this time period, we observe an increasing trend in investment as in 1990s until the recent financial crisis. In Panel B of Figure 1, we observe a similar tendency among I/K_H and I/K_C, however, we confirm our findings in Table I and observe that I/K_C is relatively more volatile than its counterpart. It is an evident fact that investment proxy from CRSP-Compustat universe is relatively more seasonal than the alternative measures.

[Figure 2 about here]

Regarding the various q-proxies, alternative $q^{classic}$ measures and q^{merton} follow similar time series patterns as reported in Figure 2. On the other hand, q^{bond} demonstrates a relatively more stable distribution over time than its counterparts as is also reported in Philippon (2009). This is one of the main reasons that we believe q^{bond} outperformed $q^{classic}$ in explaining investment. From these figures we also note that the value of an additional unit of capital increases after the first Gulf War and this value reaches its peak around the tech bubble. Although $q^{classic}$ and q^{merton} measures follow a similar variation over time, $q^{classic}\_P$ is almost always higher in value than the others.

[Figure 3 about here]

We plot the time series distribution of aggregate cash flow measure in Figure 3 and observe that it is a significantly seasonal measure over time span. Although often it varies around a constant mean, this mean value is relatively different in earlier years than later ones, specifically around the first Gulf War, Dot.com crash and the recent financial crisis there are observable structural breaks in its distribution. In fact, it reaches to a negative level in early 1990s which then gradually increases over time until the Iraq War. Aggregate cash flow level reaches to its lowest value during the recent financial crisis.

[Figure 4 about here]

Among the other variables that are documented to be closely associated with investment, especially the ones that are relevant to q^{bond}, we find that the spread between corporate and treasury bond yields and idiosyncratic volatility have the most pronounced similarity in variation as we report in Figure 4. Since by construction spread and ratio measures are highly correlated (-94.2%), they also appear counter-cyclical to each other in our data sample.[22] Similarly, real risk free rate is a function of inflation and hence these measures follow similar trend over time with different variations from each other. On the other hand, real discount factor, which is the inverse function of inflation measure, has an increasing rather than decreasing trend over the same time period. Leverage shows an increasing trend over-time from its lowest levels of 20% in mid-1980s to its highest levels in the post-financial crisis period.

[Table II about here]

In Table II we report the pairwise correlations between the main variables of interest. Among its alternatives, q^{merton} has the highest correlation with I/K_H of 81.6%, whereas q^{bond} has the lowest correlation with this variable of 64.9%. Investment has 71.6% correlation with $q^{classic}\_H$ at 1% significance level. It is important to emphasize that we observe qualitatively similar pairwise correlations between alternative q-measures and I/K_P, while q^{merton} has significant 75.4% correlation with this investment rate. Further, except for $q^{classic}\_H$ and

[22]As in Philippon (2009), Ratio$=\frac{0.1+r^{10}}{0.1+y^{Baa}} = \frac{0.1+r^{10}+y^{Baa}-y^{Baa}}{0.1+y^{Baa}} = 1 + \frac{r^{10}-y^{Baa}}{0.1+y^{Baa}} = 1 - \frac{Spread}{0.1+y^{Baa}} \approx 1 - k * Spread.$

$q^{classic}\_P$, the highest correlation among alternative q-measures exists in between $q^{classic}\_H$ and q^{merton}, which is approximately around 87.7%. These corresponding correlations are all statistically significant.

In addition to these findings, q^{bond} is positively correlated with the real risk free rate and expected inflation, whereas negatively correlated with real discount factor and bond spreads at 1% significance level. On the other hand, q^{merton} is positively correlated with book leverage and idiosyncratic volatility, and negatively correlated with inflation rate. A similar correlation structure is also observed between the alternative $q^{classic}$ measures, book leverage, idiosyncratic volatility, real discount factor, real risk free rate and inflation rate. The correlation between $q^{classic}\_P$ and relative price of treasury and corporate bonds is negative at 1% significance level. On the other hand, I/K_H is negatively correlated with bond spreads and the inflation rate, whereas I/K_P has no correlations with these variables at the conventional level of significance.

[**Table III about here**]

CRSP-Compustat universe consists only publicly traded firms. Constructed sample from this universe does not contain information about the non-public US entities, which may have a significant impact on our analysis. In order to alleviate this concern we present correlation structure between CRSP-Compustat based measures, i.e. I/K_C with other variables in Table II and Table III.

We find that I/K_C manages to capture more than 70% of the variation in alternative investment measures from 1985 to 2007 as well as in the extended sample from 1985 to 2012. Although both q^{merton} and I/K_C measures are constructed by using the same sample of data, correlation between q^{merton} and I/K_H is higher than correlation between q^{merton}

and I/K_C. Although q^{bond} has 73.7% correlation with I/K_C during 1985 to 2007, its components other than credit spread and relative price of treasury and corporate bonds are not correlated with the investment rate at the conventional level of significance. In Table III, we also find that cash flow and alternative investment measures are significantly correlated with each other.

Overall, these results confirm our initial motivation that q^{merton} might be an ideal candidate in explaining investment dynamics. Specifically its association with investment may partially come from channels other than the ones identified by the prior literature. We turn to exploring these findings more in detail in the remaining parts of this paper.

A. *Standard Investment Regressions in Levels*

We report our regression results of a simple investment model (6) along with the corresponding adjusted R^2 of each model in Table IV. Newey-West standard errors are adjusted for autocorrelation up to four lags while we denote 1% and 5% significance levels with ** and *, respectively. Constant terms are included in all regressions but are not reported in the tabulated results. In order to check the potential multicollinearity problem due to the correlation structure among alternative q-proxies, we also report corresponding variance inflation factor (VIF) test scores for each variable whenever they are necessary.

One of the most important results in Panel A of Table IV is that q^{merton} explains 66% of the variation in I/K_H, which is approximately 60% and 31% higher than the levels of variation captured by its alternatives such as q^{bond} and $q^{classic}\_H$, respectively. Reported results of Models I-III indicate that the estimated slope coefficients are all statistically significant at 1% level. In fact, an increase in $q^{classic}$, q^{bond} and q^{merton} by a one standard deviation would lead to an increase in investment rate of 0.264%, 0.239% and 0.300% per quarter, respectively.

In Models IV-VI we perform horse races in between alternative measures where we jointly include two different proxies of $q^{average}$ in each regression model. In Model IV, both $q^{classic}$ and q^{bond} explain I/K_H at 1% significance level, which suggests these two proxies are potentially capturing different information about the value of investment. On the other hand, Models V and VI show that q^{merton} performs best among its alternatives in explaining variation in I/K_H since it appears as the only variable that is statistically significant at the conventional level while not raising severe concerns about potential multicollinearity problem in model specifications. When we include both q^{bond} and q^{merton} simultaneously in Model V, adjusted R^2 increases by 3%, which yields the highest goodness-of-fit of a model in Table IV.

[Table IV about here]

We also check the robustness of these findings by using I/K_P and report the results in Panel B of Table IV. The results are qualitatively similar. In Panel B, we observe that q^{merton} continues to outperform its alternatives by yielding the highest adjusted R^2 in Model III. However in Model V, q^{bond} appears to be a significant factor in explaining the aggregate investment level at 5% significance level even when we control for q^{merton}. We believe this result is mainly driven by the underlying assumption of depreciation rate, and hence may influence the corresponding capital stock accumulation process. This intuition is also in line with the discrepancy between results in Panel A and Panel B. Finally, average VIF test scores for each model are less than the conventional threshold value of 10, which indicates that multicollinearity is not a major problem in our empirical approach.

B. Multivariate Regressions in Levels

We analyze the performance of q^{merton} in explaining the variation in I/K against some of the other factors that are documented to be associated with investment in prior literature, i.e. bond spread, ratio of treasury and corporate bond yields, inflation rate, real risk free rate, book leverage, and idiosyncratic volatility. These variables are the key ingredients of q^{bond} as reported in Philippon (2009) and will help us in reconciling our findings in Table IV. Our analyses adopt a similar framework as in equation (6) in multivariate settings. Similarly to the previous table, we use alternative investment measures, I/K_H and I/K_P as the response variables to ensure the robustness of our findings and report the corresponding results in Panel A and Panel B of Table V, respectively. Further, in order to ensure that our results do not suffer from multicollinearity and autocorrelation, we report the autocorrelation adjusted Newey-West standard errors along with the corresponding VIF test scores of each model accordingly.

[Table V about here]

Results in Panel A of Table V indicate that spread is negatively and book leverage is positively associated with I/K_H at the 1% statistical level in Models I and II. However, once we control the effect of q^{merton} in Models III and IV, we find that q^{merton} is statistically significant at 1% level in explaining the variation of investment. In these regression models spread and book leverage lose their statistical significance. Although model specifications are different from each other in Models III and IV, i.e. term structure effect on investment is controlled in various forms, q^{merton} manages to obtain a consistent level of association with the response variable, 0.718% vs. 0.727% respectively.

In Model IV, we find that idiosyncratic volatility and real discount factor are negatively, and book leverage is positively associated with investment at 5% significance level, which suggest that these associations are coming through the channels other than the one captured by q^{merton}. It is also important to note that the adjusted R^2 of these regression models rise to 79% from 40% once q^{merton} is included. VIF test results at the component level as well as on average again indicate that none of the models is subject to serious multicollinearity problem at the conventional level.

These findings are also confirmed in the results of Panel B, which we use an alternative investment measure, I/K_P as the response variable. In Panel B, q^{merton} appears to be significant at 1% level and it is positively associated with investment with a coefficient of 0.02. This observation is consistent across alternative regression model specifications in Models III and IV. Spread and idiosyncratic volatility become significantly associated with investment once we add q^{merton} as a control variable. In Model II and IV we document that real discount factor has a negative impact on the response variable at 1% significance level. Book leverage on the other hand lose its explanatory power once q^{merton} is included in our regressions. Overall, these findings confirm our previous results presented in Table IV. They suggest that q^{merton} has significant power in explaining aggregate level of investment since the estimated sign of slope coefficient is in line with the predictions of underlying theory and the amount of variation in investment being explained by a model increased from 27% to 76% with this new q-measure.

IV. Robustness

In this section we perform various sets of analyses to check the robustness of our findings. First we test the power of q^{merton} in explaining investment dynamics in the context of investment-to-cash flow sensitivities. Second, we use aggregate level of I/K measure from the CRSP-Compustat sample that is subject to the same selection criteria as we measure q^{merton}. We also extend the I/K_H measure until the last quarter of 2012 to confirm our findings are not time period specific.[23] With the extended data sample, we analyze the structural consistency of our findings specifically during the extreme impact of recent financial turmoil. Further, we perform differenced investment regressions at the aggregate level after we take the four-quarter difference of each variable in our empirical specifications in levels. This will ensure us to address potential seasonalities in our time series variables. Finally, we provide the robustness of our findings by relaxing some of the filters that we applied in obtaining sample data from CRSP-Compustat universe.

A. *Investment-to-Cash Flow Sensitivities*

Cash flow has been documented as an important factor in explaining investment over the last several decades. Whether its empirical explanatory power comes from the imperfections in capital markets, i.e. technological and financial frictions, or measurement errors in variables is still a debatable issue at the firm, industry or aggregate level, and cash flow is often used as an indicator of a disappointment in standard regression models (e.g., Bernanke and Gertler (1989), Fazzari et al. (2000), Alti (2003), Gomes (2001), Erickson and Whited (2006), and Philippon (2009)).[24] Hence, in this set of analyses we analyze the empirical performance of $q^{classic}\_H$ and q^{merton} in the standard setting while controlling the aggregate level of cash flow as an additional variable. Similar to our previous approach we control for

[23] Since Philippon's (2009) measure of I/K is only available to us until 2007 we rely on Hall's (2001) measures for this set of analyses.

[24] Among many scholars, Philippon (2009) also recognized the importance of empirical performance of newly proposed q-measures, i.e. q^{bond}, in investment regressions while controlling the profit rate in his simulated data. Due to his findings and data availability we do not report corresponding test results regarding to q^{bond}.

potential autocorrelation problems by reporting the associated Newey-West standard errors whenever they are necessary.

[Table VI about here]

In Table VI we provide our results along with the average VIF scores of each model in order to testify that the regression specifications do not suffer from multicollinearity problems. In Panel A we use I/K_H as the dependent variable and according to Model I an increase in $q^{classic}\_H$ by a one standard deviation would lead to an increase in investment rate of 0.333% per quarter. In Model II, $q^{classic}\_H$ still appears to be an important factor in explaining investment and manages to capture part of the investment dynamics even after we control for the investment-to-cash flow sensitivity. In fact, according to our findings the adjusted R^2 of a model only improves by 8% when cash flow is added as an additional independent variable.

In Models III and IV, we use q^{merton} as a proxy for the marginal value of investment instead of $q^{classic}\_H$. The goodness-of-fit of Model III is very close to the reported value in Table IV, which suggests that q^{merton}'s explanatory power is not time specific and even sustained during the recent financial crisis. Although cash flow is still significantly associated with investment at 5% significance level in Model IV, including this variable in the regression only increases explanatory power of the model by 2%. Furthermore, estimated investment-to-cash flow sensitivity in Model IV is significantly smaller than what is observed in Model II. These results suggest that our framework manages to capture the substantial part of the investment-to-cash flow sensitivities at the aggregate level.

Since both cash flow and q^{merton} are mainly constructed by using data from CRSP-Compustat universe, we perform the similar set of analyses by using an investment variable that comes from the same sample. We believe this approach aligns the information set for each measure in our specification. The reported results in Panel B are more in favor of the empirical power of alternative $q^{average}$ measures in explaining investment dynamics. Estimated investment sensitivities with respect to $q^{average}$ measures are much higher than they are documented in Panel A. For instance, an increase in $q^{classic}\_H$ and q^{merton} by a one standard deviation would lead to an increase in investment rate of 0.540% and 0.809% per quarter, respectively. Although cash flow is still a significant factor in explaining investment in Model II where we control for $q^{classic}\_H$, it loses its significance in Model IV at the conventional level. In Model II, an increase in cash flow by a one standard deviation would lead to an increase in investment rate of 0.316% per quarter. Further, when we include cash flow in our empirical specification the adjusted R^2 drops by 0.2% in Model IV, which shows that the extra explanatory power given by cash flow cannot offset the cost of losing one degree of freedom. Finally we note that q^{merton} manages to capture higher amount of variation in investment level than $q^{classic}\_H$ in Panel B, i.e. 49.6% vs. 21.8% respectively.

B. *Differenced Regressions*

In order to control for other potential econometric problems, e.g. persistency in variables, that are not completely detected and resolved in our empirical approach, we perform differenced regressions where we use the four-quarter difference of dependent and independent variables in investment regressions and report the results in Table VII. Our findings of the four-quarter differenced investment measure of Hall (2001) are tabulated in Panel A, whereas the results from CRSP-Compustat universe are presented in Panel B. Consistent with previous results we also control for autocorrelation and report the associated Newey-West standard errors accordingly. Finally we report the average VIF score of each model to alleviate the concern of potential multicollinearity problem.

[**Table VII about here**]

In Panel A of Table VII, we observe both measures of $q^{average}$ in differences are significantly associated with differences in investment at 1% statistical level according to the results in Models I and II. The estimated slope coefficients and obtained adjusted R^2s are very similar to each other in these models when we use $q^{classic}\_H$ or q^{merton} as a proxy for the marginal value of investment. Similar finding is also confirmed in Model III in which we include both variables as regressors. While they both lose their statistical power in explaining investment and adjusted R^2 only increase by 3% from its corresponding values in Model I and II. In Models IV to VI, we observe that cash flow is no longer a significant variable, which suggests that some of our significant findings in Panel A of Table VI might be due to the seasonality in cash flow measure. Overall these findings confirm the suggestion that cash flow is not a related factor in explaining aggregate level of investment, at least not at the conventional level.

We report the regression results of differenced regression with CRSP-Compustat based measures in Panel B of Table VII. These results indicate that q^{merton} is a significant proxy in explaining investment at the aggregate level. Comparing to its alternative $q^{classic}\_H$, the explained variation in investment by q^{merton} is doubled to 15.4%. In Models IV to VI, we confirm our findings in Panel A of Table VII and document an insignificant relationship between cash flow and investment at the conventional level. In fact q^{merton} is found to be the single most important variable in explaining investment in these regression results as suggested by the underlying theory.

C. Generalized Sampling

Our sample is subject to certain selection criteria as explained more in detail in Section II.D. One potential concern is that our findings may be driven by some of the filters that we apply in obtaining final data sample. Hence, in this section we relax these constraints and analyze the robustness of our findings accordingly. We only tabulate the results regarding the investment level that is constructed by CRSP-Compustat universe. However, we achieve qualitative similar results when we use I/K_H as the response variable in this set of regressions.

[Table VIII about here]

We present regression results in Panel A of Table VIII for a different sample of CRSP-Compustat universe depending on alternative filters that we applied initially. For instance no filter sample also includes the firms that have asset tangibility less than 20%. In all four models, we observe that q^{merton} is positively associated with I/K_C at 1% significance level. In Panel B, we observe that investment-to-cash flow sensitivities do not exist across different samples which confirms our findings in Table VI. We also observe that the effect of our proposed measure is much larger on investment for the sample of firms that satisfies both constraints. It yields around 50% adjusted R^2 as we restrict our sample to certain extend. When we apply both filters and control for cash flow, the adjusted R^2 decreases slightly from its value in Panel A. In addition, a one standard deviation increase in q^{merton} is associated with a 0.809% increase in investment rate, which corresponds to a 20% increase in investment at its mean.

One potential explanation of our results is that as in Peters and Taylor (2016) some of these firms rely significantly more on intangible capital rather than tangible capital, and hence not satisfying the underlying assumptions of q-theory of investment. Alternative to this explanation is that these firms do not satisfy the underlying assumptions of Merton (1974) option pricing framework, which we discuss more in detail in the next section. However, we believe it will be interesting to explore more on these issues in future research.

V. Economic Interpretation

Our results so far confirm our initial intuition of using a structural approach to construct a $q^{average}$ measure to explain the variation of investment at the aggregate level. In this section of analyses, we try to link the explanatory power of proposed measures to economically imbedded factors that might affect investment decisions of economic agents by focusing on firm level characteristics in our sample. We believe these analyses will also help us to identify the potential weaknesses of our methodology and suggest potential avenues for future research in obtaining a better proxy for the marginal value of investment.

[Table IX about here]

In Table IX, we report the median value of the sample characteristics of all firms that are sorted and assigned into three different groups depending on the deviation between corresponding market and book value of their debt.[25,26] We perform this sorting procedure in each quarter for every firm from 1985 to 2012. Hence, the 'Small' group represents the firms with the smallest amount of deviations between market and book value of their debt, and vice versa. We observe a monotonic trend across different groups in regards to their

[25]We define market value of debt as the difference between market value of asset that we obtain from Merton's (1974) option pricing model and market value of equity.

[26]In order to obtain this sample, we relax all restrictions of at least 20% tangibility in assets and deviations between market value of debt and book value of debt in our data sampling.

expected default probability, book leverage, size, q^{merton}, and their asset tangibility.[27]

Specifically, firms that are assigned to the 'Small' group have statistically lower leverage and lower asset tangibility but a higher q^{merton} with respect to their counterparts. It is also consistent that median expected default probability in this group is also the lowest. The economic value of our approach is mostly embedded in the sample of firms that are relatively risky and with more tangible capital, since we observe the largest discrepancy between the estimated market value of debt and its book value among these firms. In Panel B of Table IX we restrict our sample to those with S&P's credit ratings and also realize that risky firms have a larger difference between market value and book value of their debt.

[Table X about here]

In Table X, we perform a similar analysis as in Table IX by clustering firms into ten different groups by using their S&P's credit ratings. For instance, Group 0 includes firms that have no rating, whereas Group 9 includes the top investment grade firms. We find that the largest deviation between market value of debt and its book value is mostly observed in the group of non-investment grade firms, such as the firms in Groups 3-6. Considering the number of observations in each group and given the restriction of 20% asset tangibility that we use in our analyses, the findings on the performance of q^{merton} largely comes from the non-investment grade firms. This finding also confirms the observations of Jones et al. (1984) and Eom et al. (2004), who state that the variation in predicted errors between realized and estimated yield spreads of Merton's (1974) model performs better for this type of firms. It remains for future research to explore further on these issues to improve existing methodologies to determine the fundamental value of investment.

[27] We define book leverage in this section of firm level analyses as the ratio of book value of debt and total asset.

VI. Conclusion

In this paper we adopt Merton's (1974) option pricing model to estimate a firm's asset value, which is then used to study the implementation of q-theory of investment. During the period of 1985-2007 (1985-2012), our new measure, q^{merton}, manages to explain around 66% (64%) variation in the aggregate level of investment in the U.S. economy. Some other variables that are documented to be significantly associated with investment lose their explanatory power once q^{merton} is controlled in a standard investment regression model. These results are robust during the recent financial crisis as well as alternative investment measures in a sample of firms that are risky or having high levels of physical capital.

Overall, our results support the view of measurement error problems in the regressors of standard investment model. After we obtain a more accurately measured market value of a firm's assets, explanatory power of q^{merton} increases significantly and carries more economic value in explaining investment choices of economic agents. Although we manage to capture much of the variation in investment with our measure at the aggregate level, it is still possible to modify the proposed framework in this paper to obtain a better proxy for marginal value of investment in a wider set of firms, i.e. firms with higher levels of intangible capital stock. For instance, a potential avenue of research is to analyze how the Merton's (1974) pricing framework performs once other debt equivalent liabilities are incorporated into this framework, e.g. operating leases. Within a similar context, it remains for future research to explore in further detail whether or not the investment models at the firm level can be improved by addressing measurement errors in variables.

Appendix A. Market Value of A Firm's Assets

In this section we explain the details of derivation of firm value by using Merton's (1974) option pricing model. At time t, suppose the firm has a book value of liability L_t with time to maturity T that pays zero coupons. The firm's value at the maturity is $V_{A,t+T}$. Hence, the probability of default will be the probability that $V_{A,t+T}$ is less than L_t.

Under Merton's framework, at any time t, the value of the firm $V_{A,t}$ follows a geometric Brownian Motion:

$$dV_{A,t} = \mu_A V_{A,t} dt + \sigma_A V_{A,t} dW_t \tag{A1}$$

where W_t is a standard Wiener process. $dW_t = \varepsilon_t \sqrt{dt}$, $\varepsilon_t \sim N(0,1)$.

Hence, the value of the firm at time $t+T$ is the following:

$$\ln V_{A,t+T} = \ln V_{A,t} + (\mu_A - \frac{1}{2}\sigma_A^2)T + \sigma_A \sqrt{T} \varepsilon_{t+T} \tag{A2}$$

where $\varepsilon_{t+T} = \frac{W_{t+T} - W_t}{\sqrt{T}} \sim N(0,1)$.[28]

[28] If we ignore subscript t and A, (A1) can be written as

$$dV = \mu V dt + \sigma V dW$$

let $G(V,t) = \ln V$, by the Taylor series expansion rule

$$dG = \frac{\partial G}{\partial V} dV + \frac{\partial G}{\partial t} dt + \frac{1}{2} \frac{\partial^2 G}{\partial V^2} dV^2 + (high\ order\ terms)$$

where $\frac{\partial G}{\partial V} = \frac{1}{V}$, $\frac{\partial G}{\partial t}$=0, and $\frac{\partial^2 G}{\partial V^2} = -\frac{1}{V^2}$.

$$dG = \frac{1}{V}(\mu V dt + \sigma V dW) + \frac{1}{2}(-\frac{1}{V^2})\sigma^2 V^2 dt = (\mu - \frac{1}{2}\sigma^2)dt + \sigma dW$$

We can also drive (A2) by using Ito's lemma.

Therefore, probability of default can be written as

$$\begin{aligned}
\mathrm{P}_{\text{default}} &= \mathrm{P}[\ln(V_{A,t+T}) \leq \ln(L_t)] \\
&= \mathrm{P}[\ln V_{A,t} + (\mu_A - \frac{1}{2}\sigma_A^2)T + \sigma_A^2\sqrt{T}\epsilon_{t+T} \leq \ln(L_t)] \\
&= \mathrm{P}(\epsilon_{t+T} \leq -\frac{\ln(\frac{V_{A,t}}{L_t}) + (\mu_A - \frac{1}{2}\sigma_A^2)T}{\sigma_A^2\sqrt{T}}) \\
&= \mathrm{N}(-\frac{\ln(\frac{V_{A,t}}{L_t}) + (\mu_A - \frac{1}{2}\sigma_A^2)T}{\sigma_A^2\sqrt{T}}) = \mathrm{N}(-DD_t)
\end{aligned}$$

where DD_t is known as distance to default. Hence,

$$\mathrm{DD}_t = \frac{\ln(\frac{V_{A,t}}{L_t}) + (\mu_A - \frac{1}{2}\sigma_A^2)T}{\sigma_A\sqrt{T}}.$$

In order to calculate DD_t, one needs to know $V_{A,t}$, σ_A, and μ_A, which are not directly observable from the data. However, they can be estimated by using the option pricing model which treats a firm's equity as a call option written on the firm's assets with strike price, L_t, and time to maturity T. Firm's value to equity-holders at time t is

$$\mathrm{V}_{E,t} = \max\left[\mathrm{V}_{A,t} - \mathrm{L}_t, 0\right]$$

and, firm's value to debt-holders at time t is

$$\mathrm{V}_{D,t} = \min\left[\mathrm{V}_{A,t}, \mathrm{L}_t\right] = \mathrm{L}_t - \max\left[\mathrm{L}_t - \mathrm{V}_{A,t}, 0\right]$$

which are similar to European call option payoffs.

By using Black and Scholes's (1973) and Merton's (1974) option pricing frameworks, firm's equity value at time t is the following:

$$\mathrm{V}_{E,t} = \mathrm{V}_{A,t}\mathrm{N}(\mathrm{d}_1) - \mathrm{L}_t e^{-rT}\mathrm{N}(\mathrm{d}_2) \tag{A3}$$

where $N(.)$ is the cumulative density function of standard normal distribution, $\mathrm{d}_1 = \frac{\ln(\frac{V_{A,t}}{L_t})+(r+\frac{1}{2}\sigma_A^2)T}{\sigma_A\sqrt{T}}$, $\mathrm{d}_2 = \mathrm{d}_1 - \sigma_A\sqrt{T}$, and r is instantaneous risk-free rate.

Since $V_{E,t}$ is a function of $V_{A,t}$ and t, then

$$\begin{aligned} dV_{E,t} &= \frac{\partial V_{E,t}}{\partial V_{A,t}}dV_{A,t} + \frac{\partial V_{E,t}}{\partial t}dt + \frac{1}{2}\frac{\partial^2 V_{E,t}}{\partial V_{A,t}}dV_{A,t}^2 + (high\ order\ terms) \\ &= \mathrm{N}(d_1)dV_{A,t} + \frac{\partial V_{E,t}}{\partial t}dt + \frac{1}{2}\frac{\partial^2 V_{E,t}}{\partial V_{A,t}}{\sigma_A}^2{V_{A,t}}^2dt \qquad \text{(A4)} \\ &= \mathrm{N}(d_1)\mu_A V_{A,t}dt + \sigma_A V_{A,t}\mathrm{N}(d_1)dW_t + \left[\frac{\partial V_{E,t}}{\partial t} + \frac{1}{2}\frac{\partial^2 V_{E,t}}{\partial V_{A,t}}\right]dt \\ &= \left[\mathrm{N}(d_1)\mu_A V_{A,t} + \frac{\partial V_{E,t}}{\partial t} + \frac{1}{2}\frac{\partial^2 V_{E,t}}{\partial V_{A,t}}\right]dt + \sigma_A V_{A,t}\mathrm{N}(d_1)dW_t. \qquad \text{(A5)} \end{aligned}$$

where we use the Taylor series expansion rule to derive (A4), such that

$$\frac{\partial V_{E,t}}{\partial V_{A,t}} = N(d_1) + V_{A,t}\frac{N(d_1)}{\partial V_{A,t}} - L_t e^{-rT}\frac{N(d_2)}{\partial V_{A,t}}$$

If we recall $N(d) = \int_{-\infty}^{d} f(x)dx$, where $f(x) = \frac{1}{\sqrt{2\pi}}e^{-\frac{x^2}{2}}$, and denote $N = N(d)$, and $d = d(V)$ for simplicity, then by using chain-rule

$$\frac{\partial N}{\partial V} = \frac{\partial N}{\partial d}\frac{\partial d}{\partial V} = \frac{\partial N}{\partial x}\bigg|_{x=d}\frac{\partial d}{\partial V} = f(x)\bigg|_{x=d}\frac{\partial d}{\partial V} = f(d)\frac{\partial d}{\partial V}.$$

which implies, $\frac{\partial N(d_1)}{\partial V_{A,t}} = f(d_1)\frac{\partial d_1}{\partial V_{A,t}} = f(d_1)\frac{1}{V_{A,t}\sigma_A\sqrt{T}}$, and similarly, $\frac{\partial N(d_2)}{\partial V_{A,t}} = f(d_2)\frac{1}{V_{A,t}\sigma_A\sqrt{T}}$.

Therefore,

$$V_{A,t}\frac{\partial N(d_1)}{\partial V_{A,t}} = \frac{1}{\sigma_A\sqrt{2\pi T}}e^{-\frac{{d_1}^2}{2}} \tag{A6}$$
$$L_t e^{-rT}\frac{\partial N(d_2)}{\partial V_{A,t}} = \frac{L_t}{V_{A,t}\sigma_A\sqrt{2\pi T}}e^{-rT-\frac{{d_2}^2}{2}}. \tag{A7}$$

If we take logarithm of (A6) and (A7), we have

$$\ln\left[V_{A,t}\frac{\partial N(d_1)}{\partial V_{A,t}}\right] = -\ln(\sigma_A\sqrt{2\pi T}) - \frac{{d_1}^2}{2} \tag{A8}$$
$$\ln\left[L_t e^{-rT}\frac{\partial N(d_2)}{\partial V_{A,t}}\right] = -\ln(\sigma_A\sqrt{2\pi T}) + \ln\left(\frac{L_t}{V_{A,t}}\right) - rT - \frac{{d_2}^2}{2} \tag{A9}$$

Subtracting (A9) from (A8), we get

$$\begin{aligned}
\frac{d_2^2 - d_1^2}{2} + rT + \ln\left(\frac{V_{A,t}}{L_t}\right) &= \frac{(d_2 - d_1)(d_2 + d_1)}{2} + rT + \ln\left(\frac{V_{A,t}}{L_t}\right) \\
&= \frac{2\ln\left(\frac{V_{A,t}}{L_t}\right) + 2rT}{2\sigma_A\sqrt{T}}(-\sigma_A\sqrt{T}) + rT + \ln\left(\frac{V_{A,t}}{L_t}\right) \\
&= -\ln\left(\frac{V_{A,t}}{L_t}\right) - rT + rT + \ln\left(\frac{V_{A,t}}{L_t}\right) = 0.
\end{aligned}$$

which implies $\frac{\partial V_{E,t}}{\partial V_{A,t}} = N(d_1)$.

Now, we can write the dynamics of $V_{E,t}$ as

$$dV_{E,t} = \mu_E V_{E,t}dt + \sigma_E V_{E,t}dW_t \tag{A10}$$

By using equations (A10) and (A5), we can obtain

$$\sigma_E V_{E,t} = \sigma_A V_{A,t} N(d_1).$$

and it implies

$$\sigma_E = \left(\frac{V_{A,t}}{V_{E,t}}\right) N(d_1) \sigma_A. \tag{A11}$$

Hence, $P_{default}$, $V_{A,t}$, and σ_A can be obtained by solving (A3) and (A11) iteratively.

Appendix B. Firm's Assets and Components

Table A.I
Mean value of assets

This table provides the mean value of firms' assets and asset components that are included and excluded by tangibility filter in our sample from 1985 to 2007. Missing values are treated as zero.

	Firms with Tangibility>=0.2		Firms with Tangibility<0.2	
	Level(Millions)	Percent	Level(Millions)	Percent
Assets - Total	995.64	100.0%	701.38	100.0%
Current Assets - Total	245.72	24.7%	197.38	28.1%
Cash and Short-Term Investments	52.56	5.3%	54.59	7.8%
Current Assets - Other - Total	28.41	2.9%	23.81	3.4%
Inventories - Total	65.53	6.6%	75.69	10.8%
Receivables - Total	105.59	10.6%	105.17	15.0%
Property Plant and Equipment(Net)-Total	*499.50*	*50.2%*	*69.32*	*9.9%*
Intangible Assets - Total	119.62	12.0%	186.87	26.6%

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Table I

Descriptive Statistics: Quarterly Aggregate Data

Three measures of investment over replacement cost of capital net of depreciation, I/K_H, I/K_P and I/K_C are constructed as in Hall (2001), Philippon (2009), and from the quarterly Compustat-CRSP sample, respectively. $q^{classic}$_H is constructed as in Hall (2001). $q^{classic}$_P and q^{bond} are from Philippon (2009). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Cash flow is measured by the sum of firms' income before extraordinary items and depreciation and amortization, scaled by replacement cost of capital net of depreciation. Relative price of treasury and corporate bonds, credit spread, real risk free rate, book leverage, and real discount factor are constructed as in Philippon (2009). Moody's BAA rated corporate bond prices and treasury yields are from FRED. Expected inflation is from the Livingston survey. Idiosyncratic volatility is calculated as in Goyal and Santa-Clara (2003).

Panel A: 1985Q1-2007Q2

	N.Obs	Mean	Std.Dev.	Min	Max
I/K_H	90	0.0355	0.0037	0.0301	0.0428
I/K_P	90	0.1044	0.0091	0.0887	0.1254
I/K_C	90	0.0417	0.0106	0.0160	0.0652
$q^{classic}$_*H*	90	1.5488	0.5325	0.6750	3.1070
$q^{classic}$_*P*	90	2.6306	0.8674	1.2134	4.9890
q^{bond}	90	1.5357	0.0951	1.2971	1.7198
q^{merton}	90	1.6267	0.4708	0.9650	3.0893
$(0.1+r^{10})/(0.1+y^{Baa})$	90	0.8877	0.0302	0.7862	0.9319
Spread: $[y^{Baa}-r^{10}]$	90	0.0208	0.0051	0.0130	0.0379
Real risk free rate	90	0.0349	0.0115	0.0166	0.0738
Book leverage	90	0.5677	0.0717	0.4101	0.6744
Real discount factor	90	0.9675	0.0101	0.9342	0.9840
Inflation	90	0.0312	0.0089	0.0181	0.0503
Idiosyncratic volatility	90	0.2061	0.0423	0.1367	0.3134

Panel B: 1985Q1-2012Q4

	N.Obs	Mean	Std.Dev.	Min	Max
I/K_H	112	0.0347	0.0041	0.0255	0.0428
I/K_C	112	0.0398	0.0114	0.0121	0.0652
$q^{classic}$_*H*	112	1.5255	0.4953	0.6750	3.1070
q^{merton}	112	1.5314	0.4787	0.8175	3.0893
Cash Flow	112	0.0292	0.0194	-0.0590	0.0615

Table II
Pearson Correlations: Quarterly Aggregate Data, 1985Q1-2007Q2

(1) is I/K_H. (2) is I/K_P. (3) is I/K_C. (4) is $q^{classic}$_H. (5) is $q^{classic}$_P. (6) is q^{bond}. (7) is q^{merton}. (8) is $(0.1+r^{10})$ /(0.1+ y^{Baa}). (9) is credit spread: [y^{Baa}-r^{10}]. (10) is real risk free rate. (11) is book leverage. (12) is real discount factor. (13) is inflation. (14) is idiosyncratic volatility.

Three measures of investment over replacement cost of capital net of depreciation, I/K_H, I/K_P and I/K_C are constructed as in Hall (2001), Philippon (2009), and from the quarterly Compustat-CRSP sample, respectively. $q^{classic}$_H is constructed as in Hall (2001). $q^{classic}$_P and q^{bond} are from Philippon (2009). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of firms' net total property, plant and equipment. Relative price of treasury and corporate bonds, credit spread, real risk free rate, book leverage, and real discount factor are constructed as in Philippon (2009). Moody's BAA rated corporate bond prices and treasury yields are from FRED. Expected inflation is from the Livingston survey. Idiosyncratic volatility is calculated as in Goyal and Santa-Clara (2003). ** and * indicate significance at the 1% and 5% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)	1												
(2)	0.913**	1											
(3)	0.772**	0.716**	1										
(4)	0.716**	0.624**	0.486**	1									
(5)	0.672**	0.616**	0.440**	0.979**	1								
(6)	0.649**	0.631**	0.737**	0.348**	0.291**	1							
(7)	0.816**	0.754**	0.715**	0.877**	0.855**	0.627**	1						
(8)	0.254*	0.175	0.427**	-0.201	-0.305**	0.734**	0.0551	1					
(9)	-0.355**	-0.187	-0.464**	-0.00835	0.102	-0.743**	-0.178	-0.942**	1				
(10)	0.0395	0.197	0.126	-0.463**	-0.483**	0.349**	-0.184	0.584**	-0.310**	1			
(11)	0.246*	0.102	-0.0105	0.683**	0.741**	-0.204	0.385**	-0.561**	0.279**	-0.806**	1		
(12)	-0.0515	-0.207	-0.138	0.448**	0.468**	-0.361**	0.166	-0.587**	0.315**	-1.000**	0.800**	1	
(13)	-0.325**	-0.155	-0.0235	-0.722**	-0.751**	0.226*	-0.426**	0.556**	-0.285**	0.734**	-0.914**	-0.723**	1
(14)	0.151	0.205	0.100	0.389**	0.454**	0.0721	0.470**	-0.401**	0.426**	-0.0826	0.201	0.0709	-0.215*

Table III

Pearson Correlations: Quarterly Aggregate Data, 1985Q1-2012Q4

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_C are constructed as in Hall (2001) and from the quarterly Compustat-CRSP sample, respectively. $q^{classic}$_H is constructed as in Hall (2001). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of firms' net total property, plant and equipment. Cash flow is measured by the sum of firms' income before extraordinary items and depreciation and amortization, scaled by replacement cost of capital net of depreciation. ** and * indicate significance at the 1% and 5% levels, respectively.

	I/K_H	*I/K_C*	$q^{classic}$_*H*	q^{merton}
I/K_H	1			
I/K_C	0.794**	1		
$q^{classic}$_*H*	0.683**	0.475**	1	
q^{merton}	0.801**	0.707**	0.820**	1
Cash Flow	0.539**	0.424**	0.405**	0.537**

Table IV

Investment Regressions: Quarterly Aggregate Data, 1985Q1-2007Q2

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_P are constructed as in Hall (2001) and Philippon (2009), respectively. $q^{classic}$_H is constructed as in Hall (2001). $q^{classic}$_P and q^{bond} are from Philippon (2009). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

Panel A. Dependent variable in levels: I(t)/K(t-1)_H

	Model I	Model II	Model III	Model IV	Model V	Model VI
$q^{classic}$_H(t-1)	0.00496**			0.00386**		0.00000929
	(0.000855)			(0.000926)		(0.00141)
q^{bond}(t-1)		0.0252**		0.0176**	0.00878	
		(0.00462)		(0.00338)	(0.00466)	
q^{merton}(t-1)			0.00639**		0.00528**	0.00638**
			(0.000801)		(0.00118)	(0.00126)
N.Obs.	90	90	90	90	90	90
Adj.R-square	0.507	0.415	0.663	0.688	0.691	0.659
Average VIF				1.14	1.65	4.33

Panel B. Dependent variable in levels: I(t)/K(t-1)_P

	Model I	Model II	Model III	Model IV	Model V	Model VI
$q^{classic}$_P(t-1)	0.00644**			0.00494**		-0.00113
	(0.00192)			(0.00174)		(0.00228)
q^{bond}(t-1)		0.0601**		0.0470**	0.0249*	
		(0.0117)		(0.00688)	(0.00999)	
q^{merton}(t-1)			0.0145**		0.0114**	0.0163**
			(0.00259)		(0.00349)	(0.00270)
N.Obs.	90	90	90	90	90	90
Adj.R-square	0.372	0.391	0.564	0.593	0.601	0.562
Average VIF				1.09	1.65	3.72

Table V

Investment Regressions: Quarterly Aggregate Data, 1985Q1-2007Q2

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_P are constructed as in Hall (2001) and Philippon (2009), respectively. q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Relative price of treasury and corporate bonds, credit spread, real risk free rate, book leverage, and real discount factor are constructed as in Philippon (2009). Moody's BAA rated corporate bond prices and treasury yields are from FRED. Expected inflation is from the Livingston survey. Idiosyncratic volatility is calculated as in Goyal and Santa-Clara (2003). Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

Panel A

	Dependent variable in levels: I(t)/K(t-1)_H			
	Model I	Model II	Model III	Model IV
Spread: $[y^{Baa} - r^{10}](t\text{-}1)$	-0.377**		-0.0126	
	(0.120)		(0.0732)	
Real risk free rate (t-1)	0.158*		0.132*	
	(0.0649)		(0.0518)	
Idiosyncratic volatility (t-1)	0.0232	0.0216	-0.0259*	-0.0275*
	(0.0169)	(0.0166)	(0.0115)	(0.0114)
Book leverage (t-1)	0.0377**	0.0436**	0.0148*	0.0139*
	(0.0132)	(0.0122)	(0.00612)	(0.00597)
$[0.1+r^{10}]/[0.1+y^{Baa}]$ *(t-1)*		0.0727**		-0.00124
		(0.0238)		(0.0148)
Real discount factor (t-1)		-0.145		-0.148*
		(0.0805)		(0.0631)
q^{merton} *(t-1)*			0.00718**	0.00727**
			(0.000805)	(0.000807)
N.Obs.	90	90	90	90
Adj.R-square	0.397	0.390	0.786	0.783

	VIF			
Spread: $[y^{Baa} - r^{10}](t\text{-}1)$	1.35		2.03	
Real risk free rate (t-1)	3.07		3.09	
Idiosyncratic volatility (t-1)	1.29	1.29	2.14	2.13
Book leverage (t-1)	3.03	2.97	3.56	3.85
$[0.1+r^{10}]/[0.1+y^{Baa}]$ *(t-1)*		1.92		2.89
Real discount factor (t-1)		3.27		3.27
q^{merton} *(t-1)*			2.26	2.28
Average VIF	2.19	2.36	2.71	3.04

Table V—*Continued*

Investment Regressions: Quarterly Aggregate Data, 1985Q1-2007Q2

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_P are constructed as in Hall (2001) and Philippon (2009), respectively. q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Relative price of treasury and corporate bonds, credit spread, real risk free rate, book leverage, and real discount factor are constructed as in Philippon (2009). Moody's BAA rated corporate bond prices and treasury yields are from FRED. Expected inflation is from the Livingston survey. Idiosyncratic volatility is calculated as in Goyal and Santa-Clara (2003). Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

Panel B

	Dependent variable in levels: I(t)/K(t-1)_P			
	Model I	Model II	Model III	Model IV
Spread: $[y^{Baa} - r^{10}]$*(t-1)*	-0.474		0.539**	
	(0.339)		(0.188)	
Real risk free rate (t-1)	0.535**		0.464**	
	(0.175)		(0.0951)	
Idiosyncratic volatility (t-1)	0.0511	0.0482	-0.0854*	-0.0867*
	(0.0472)	(0.0463)	(0.0343)	(0.0341)
Book leverage (t-1)	0.0854*	0.0925*	0.0219	0.0109
	(0.0387)	(0.0368)	(0.0138)	(0.0124)
$[0.1+r^{10}]/[0.1+y^{Baa}]$ *(t-1)*		0.0919		-0.111**
		(0.0653)		(0.0370)
Real discount factor (t-1)		-0.564**		-0.573**
		(0.206)		(0.117)
q^{merton} *(t-1)*			0.0200**	0.0200**
			(0.00208)	(0.00206)
N.Obs.	90	90	90	90
Adj.R-square	0.268	0.272	0.764	0.763

	VIF			
Spread: $[y^{Baa} - r^{10}]$*(t-1)*	1.35		2.03	
Real risk free rate (t-1)	3.07		3.09	
Idiosyncratic volatility (t-1)	1.29	1.29	2.14	2.13
Book leverage (t-1)	3.03	2.97	3.56	3.85
$[0.1+r^{10}]/[0.1+y^{Baa}]$ *(t-1)*		1.92		2.89
Real discount factor (t-1)		3.27		3.27
q^{merton} *(t-1)*			2.26	2.28
Average VIF	2.19	2.36	2.71	3.04

Table VI

Investment Regressions: Quarterly Aggregate Data, 1985Q1-2012Q4

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_C are constructed as in Hall (2001) and from the quarterly Compustat-CRSP sample, respectively. $q^{classic}$_H is constructed as in Hall (2001). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Cash flow is measured by the sum of firms' income before extraordinary items and depreciation and amortization, scaled by replacement cost of capital net of depreciation. Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

	Panel A. Dependent variable in levels: I(t)/K(t-1)_H			
	Model I	Model II	Model III	Model IV
$q^{classic}$_*H(t-1)*	0.00559**	0.00455**		
	(0.00100)	(0.00105)		
q^{merton}*(t-1)*			0.00679**	0.00609**
			(0.000785)	(0.000938)
Cash Flow(t)		0.0656**		0.0321*
		(0.0190)		(0.0153)
N.Obs.	112	112	112	112
Adj.R-square	0.461	0.540	0.638	0.651
Average VIF		1.20		1.40

	Panel B. Dependent variable in levels: I(t)/K(t-1)_C			
	Model I	Model II	Model III	Model IV
$q^{classic}$_*H(t-1)*	0.0109**	0.00835**		
	(0.00227)	(0.00232)		
q^{merton}*(t-1)*			0.0169**	0.0161**
			(0.00226)	(0.00241)
Cash Flow(t)		0.163*		0.0365
		(0.0725)		(0.0479)
N.Obs.	112	112	112	112
Adj.R-square	0.218	0.276	0.496	0.494
Average VIF		1.20		1.40

Table VII

Investment Regressions: Quarterly Aggregate Data, 1985Q1-2012Q4

Two measures of investment over replacement cost of capital net of depreciation, I/K_H and I/K_C are constructed as in Hall (2001) and from the quarterly Compustat-CRSP sample, respectively. $q^{classic}$_H is constructed as in Hall (2001). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Cash flow is measured by the sum of firms' income before extraordinary items and depreciation and amortization, scaled by replacement cost of capital net of depreciation. Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

Panel A. Dependent variable in levels: ΔI/K_H(t,t-4)

	Model I	Model II	Model III	Model IV	Model V	Model VI
$\Delta q^{classic}$_H(t-1,t-5)	0.00442**		0.00245	0.00429**		0.00263*
	(0.00114)		(0.00140)	(0.00116)		(0.00131)
Δq^{merton}(t-1,t-5)		0.00513**	0.00290		0.00506**	0.00255
		(0.00145)	(0.00175)		(0.00164)	(0.00194)
ΔCash Flow(t,t-4)				0.0191	0.00343	0.0101
				(0.0246)	(0.0241)	(0.0252)
N.Obs.	108	108	108	108	108	108
Adj.R-square	0.259	0.260	0.285	0.266	0.253	0.282
Average VIF			2.60	1.02	1.11	2.28

Panel B. Dependent variable in levels: ΔI/K_C(t,t-4)

	Model I	Model II	Model III	Model IV	Model V	Model VI
$\Delta q^{classic}$_H(t-1,t-5)	0.00880**		-0.00183	0.00810**		-0.000888
	(0.00291)		(0.00500)	(0.00278)		(0.00519)
Δq^{merton}(t-1,t-5)		0.0140**	0.0157*		0.0129**	0.0137*
		(0.00317)	(0.00598)		(0.00357)	(0.00693)
ΔCash Flow(t,t-4)				0.104	0.0571	0.0548
				(0.0922)	(0.0867)	(0.0905)
N.Obs.	108	108	108	108	108	108
Adj.R-square	0.0770	0.154	0.148	0.103	0.156	0.148
Average VIF			2.60	1.02	1.11	2.28

Table VIII

Investment regression, 1985Q1-2012Q4

Dependent variable I/K_C and the corresponding independent variables are constructed by applying different filters on the quarterly Compustat-CRSP sample. No filter is the sample of entire Compustat-CSRP sample. Tangibility >= 0.2 is the sample of firms with asset tangibility more than or equal to 20%. Iteration >= 2 is the sample of firms with at least 2 iterations in Merton's (1974) option pricing framework. Both filters is the sample of firms that satisfies both tangibility and iteration requirements. Asset tangibility is net total property, plant and equipment divided by total asset. q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of a firm's net total property, plant and equipment. Cash flow is measured by the sum of firms' income before extraordinary items, depreciation and amortization, and deferred taxes, scaled by replacement cost of capital net of depreciation. Newey-West standard errors with autocorrelation up to 4 lags are reported in parentheses. ** and * indicate significance at the 1% and 5% levels, respectively. Constant terms are included in all regressions but are not reported in the tabulated results.

	Dependent variable in levels: I/K_C			
	Panel A			
	No filter	Tangibility>=0.2	Iteration>=2	Both filters
q^{merton}	0.00286**	0.00681**	0.0116**	0.0169**
	(0.000662)	(0.00118)	(0.00172)	(0.00226)
N. Obs.	112	112	112	112
Adj. R-square	0.233	0.358	0.398	0.496
	Panel B			
	No filter	Tangibility>=0.2	Iteration>=2	Both filters
q^{merton}	0.00358**	0.00794**	0.0108**	0.0161**
	(0.000823)	(0.00141)	(0.00201)	(0.00241)
Cash Flow	-0.0657	-0.0808	0.0417	0.0365
	(0.0444)	(0.0568)	(0.0471)	(0.0479)
N. Obs.	112	112	112	112
Adj. R-square	0.256	0.374	0.399	0.494

Table IX

Firm level characteristics

Firms are sorted into three groups by the difference between book value (BVD) and market value (MVD) of debt scaled by market value of debt. Book value of debt is the sum of short term debt and long term debt. Market value of debt is the difference between market value of asset and market value of equity. Market value of asset is from Merton's (1974) option pricing model. Market value of equity is the firm's equity price multiplied by its outstanding shares. Book leverage is measured by book value of debt divided by total asset. Asset tangibility is net total property, plant and equipment divided by total asset. q^{merton} is market value of asset divided by replacement cost of capital net of depreciation. Replacement cost of capital is the book value of a firm's net total property, plant and equipment. All variables are time series average of cross sectional median in each quarter.

Panel A. Sample of all firms (1985Q1-2012Q4)

	Sort by (BVD-MVD)/MVD		
	Small	Middle	Big
(BVD-MVD)/MVD	0.0059	0.6685	1.1778
Book Leverage	0.0196	0.2281	0.3053
Asset Tangibility	0.1158	0.2241	0.2430
Log(Total Asset)	3.8266	4.7079	5.2897
q^{merton}	14.1035	4.1072	3.2393
Probability of default	0.0000	0.0026	0.0100

Panel B. Sample of all firms with credit ratings (1985Q4-2012Q4)

	Sort by (BVD-MVD)/MVD		
	Small	Middle	Big
(BVD-MVD)/MVD	0.6364	1.0091	1.2237
Book Leverage	0.2897	0.3718	0.4093
Asset Tangibility	0.2499	0.3069	0.2994
Log(Total Asset)	7.5633	7.1523	7.0112
q^{merton}	3.6378	2.3944	2.2209
Probability of default	0.0007	0.0019	0.0295

Table X

Firm level characteristics: 1985Q1-2012Q4

Firms are sorted into 10 groups by the S&Ps Domestic Long Term Issuer Credit Ratings: AAA firms are in group 9; AA+, AA, AA- firms are in group 8; A+, A, A- firms are in group 7; BBB+, BBB, BBB- firms are in group 6; BB+, BB, BB- firms are in group 5; B+, B, B- firms are in group 4; CCC+, CCC, CCC-, CC firms are in group 3; C, D, N.M., SD, Suspended firms are in group 2; firms appeared in the rating file but with missing rating is in group 1; firms do not appear in the rating file is in group 0. Book value of debt is the sum of short term debt and long term debt. Market value of debt is the difference between market value of asset and market value of equity. Market value of asset is from Merton's (1974) option pricing model. Market value of equity is the firm's equity price multiplied by its outstanding shares. Book leverage is measured by book value of debt divided by total asset. Asset tangibility is net total property, plant and equipment divided by total asset. q^{merton} is market value of asset divided by replacement cost of capital net of depreciation. Replacement cost of capital is the book value of a firm's net total property, plant and equipment. All variables are time series average of cross sectional median in each quarter.

	Sample of all firms									
	0	1	2	3	4	5	6	7	8	9
(BVD-MVD)/MVD	0.3450	0.4845	0.7098	1.1022	1.0660	1.0389	0.9782	0.8580	0.7161	0.7193
Book Leverage	0.0514	0.1006	0.1737	0.6182	0.4691	0.3647	0.2635	0.2306	0.2088	0.1108
Asset Tangibility	0.1059	0.1569	0.3307	0.3481	0.2794	0.2553	0.2658	0.2608	0.2969	0.2181
Log(Total Asset)	4.2031	4.5011	5.7881	6.0991	6.3834	7.0730	8.0421	8.7525	9.8650	10.2017
q^{merton}	19.5680	9.0980	0.9080	1.9055	2.5151	2.8465	4.2869	5.8668	7.7556	12.9221
Probability of default	0.0001	0.0001	0.2217	0.2814	0.0143	0.0029	0.0000	0.0000	0.0000	0.0000
Percentage of Total obs	25.08	58.93	0.12	0.50	4.50	4.93	3.48	1.82	0.43	0.20

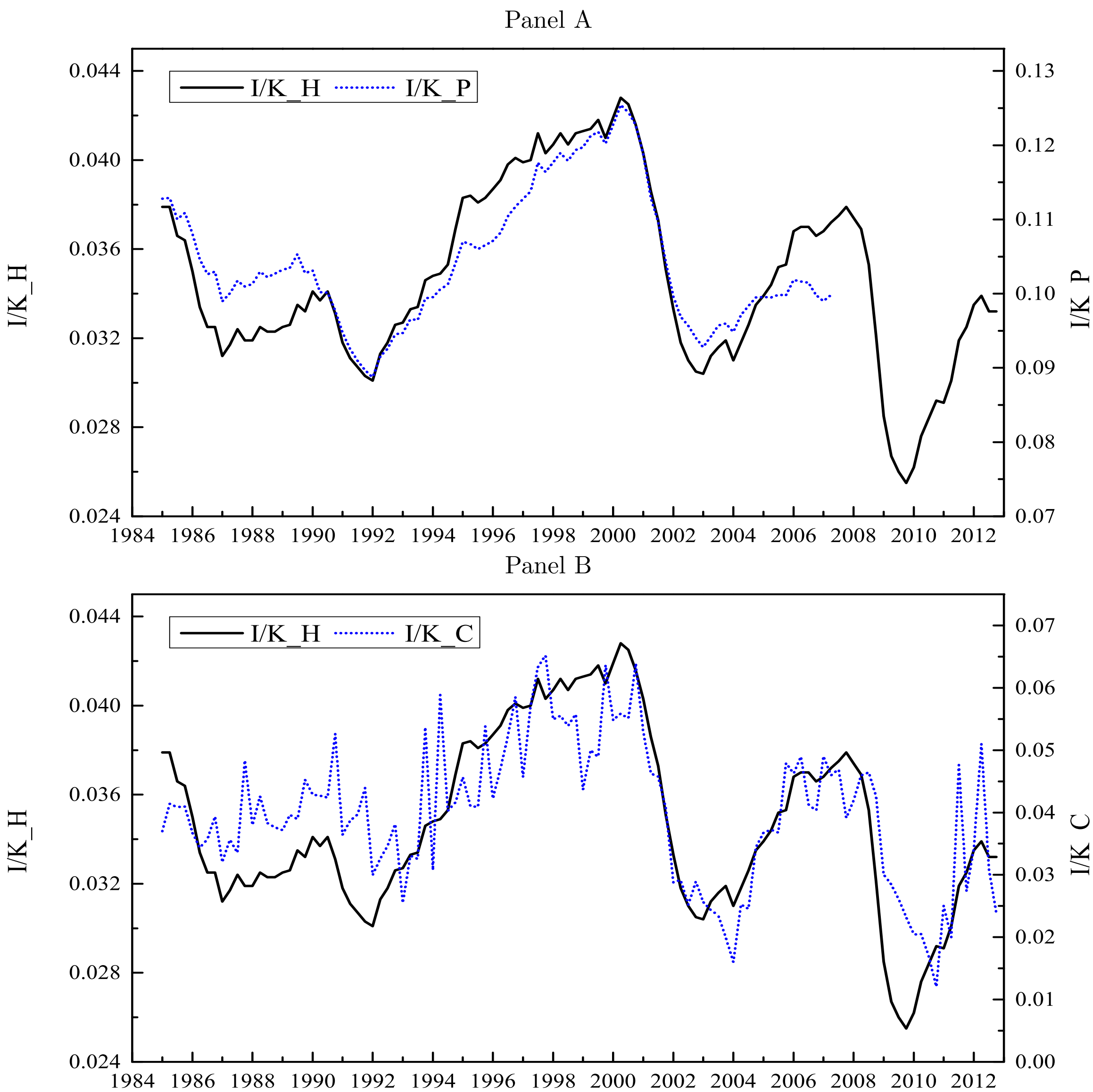

Figure 1. Alternative investment measures. Three measures of investment over replacement cost of capital net of depreciation, I/K_H, I/K_P and I/K_C are constructed as in Hall (2001), Philippon (2009), and from the quarterly Compustat-CRSP sample, respectively. Replacement cost of capital net of depreciation is the book value of firm's net total property, plant and equipment. Panel A: I/K_H vs. I/K_P; Panel B: I/K_H vs. I/K_C.

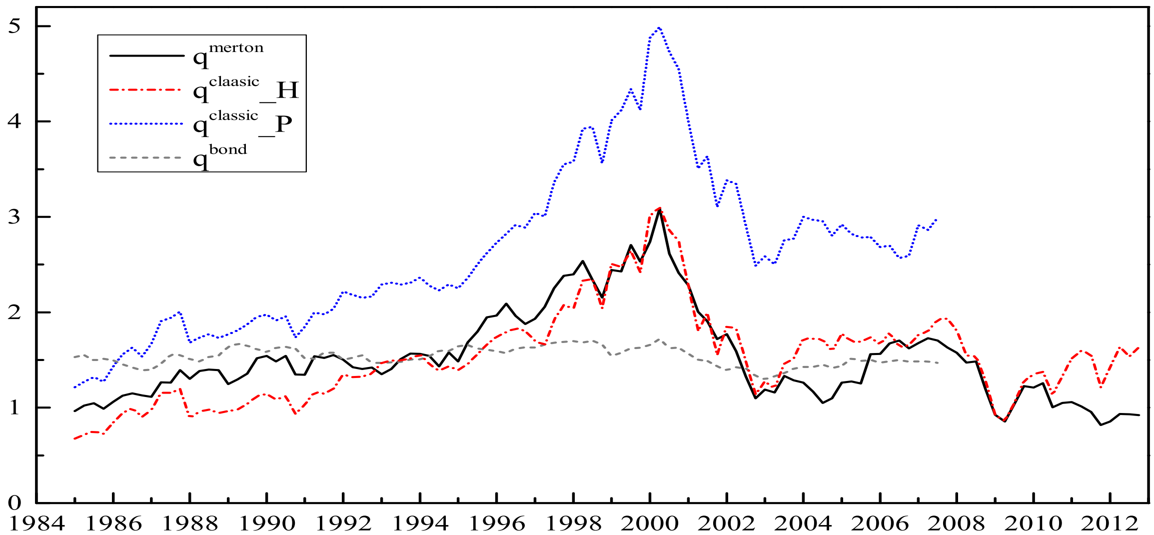

Figure 2. Alternative q measures. $q^{classic}$_H is constructed as in Hall (2001). $q^{classic}$_P and q^{bond} are from Philippon (2009). q^{merton} is the aggregate market value of firms net of inventories, scaled by aggregate replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of firm's net total property, plant and equipment.

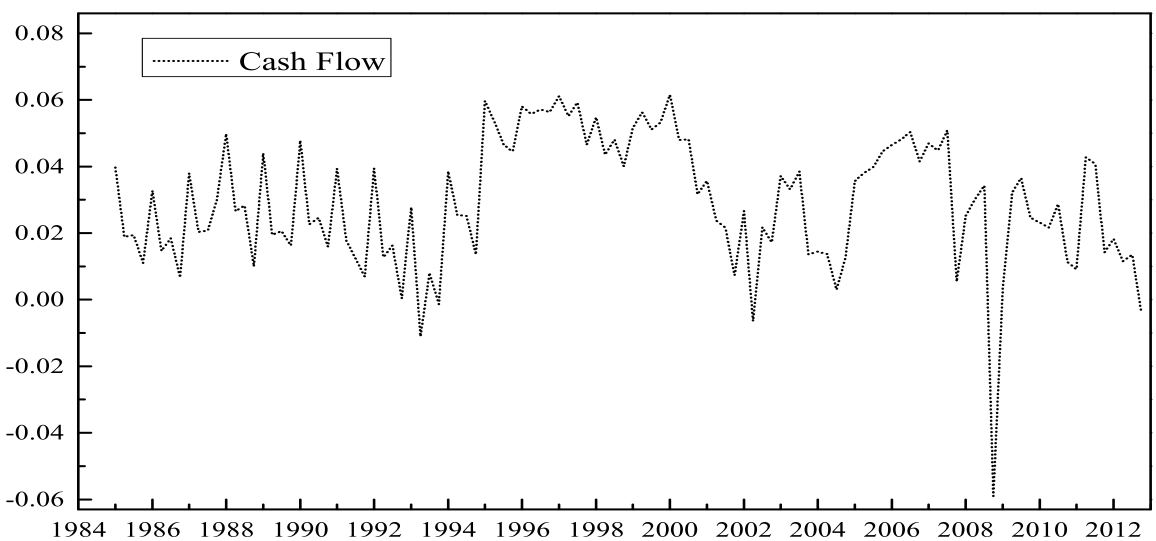

Figure 3. Cash Flow. Cash flow is measured by the sum of firm's income before extraordinary items and depreciation and amortization, scaled by replacement cost of capital net of depreciation. Replacement cost of capital net of depreciation is the book value of firm's net total property, plant and equipment.

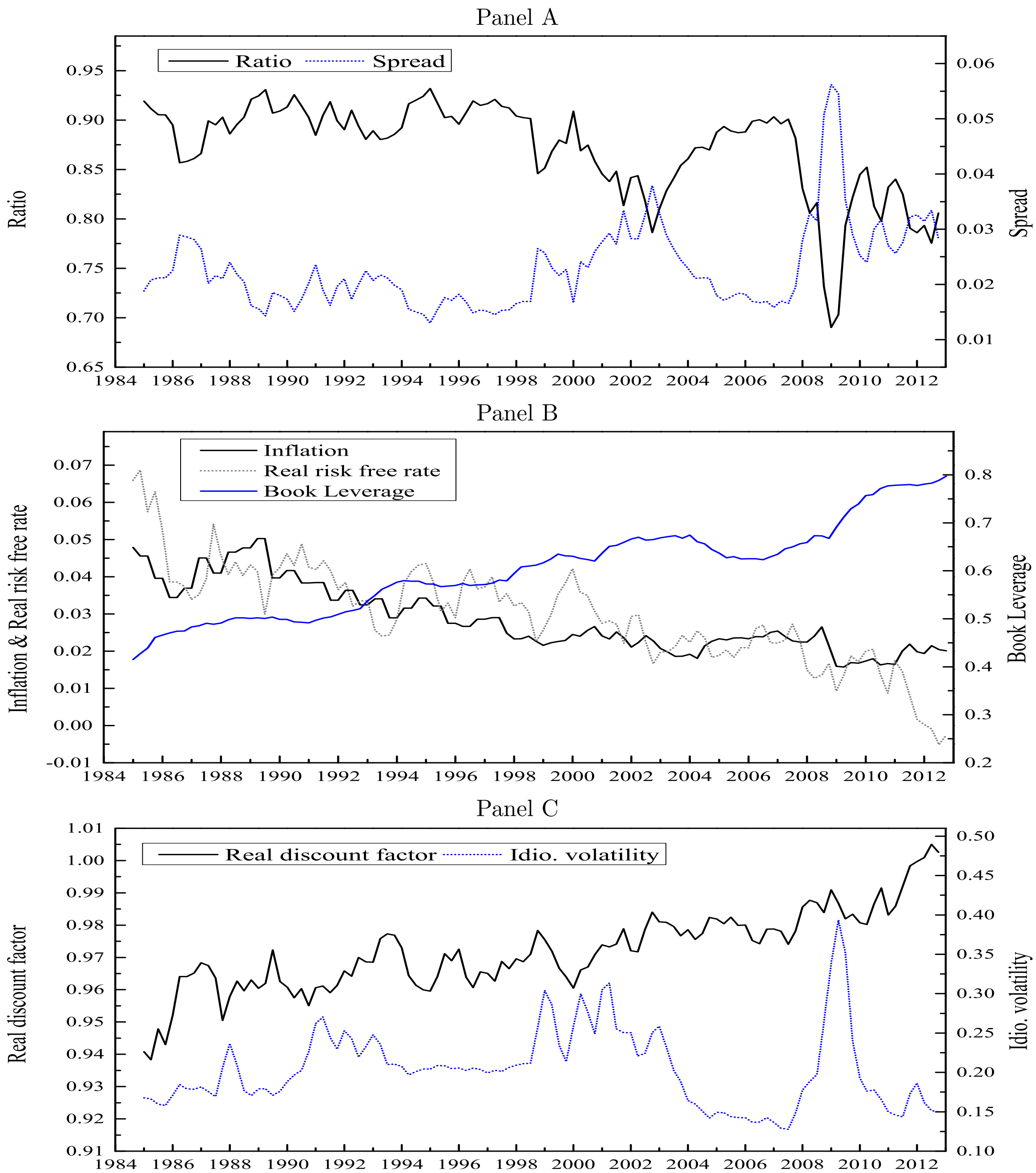

Figure 4. Other factors. Relative price of treasury and corporate bonds, credit spread, real risk free rate, book leverage, and real discount factor are constructed as in Philippon (2009). Moody's BAA rated corporate bond prices and treasury yields are from FRED. Expected inflation is from the Livingston survey. Idiosyncratic volatility is calculated as in Goyal and Santa-Clara (2003). Panel A: Ratio vs. Spread; Panel B: Inflation, Real risk free rate vs. Book leverage; Panel C: Real discount factor vs. Idiosyncratic volatility.