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Do Bubbles Lead to Overinvestment?: A Revealed Preference Approach

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Abstract

Many economists believe that the stock market plays an important role in efficiently allocating capital to its most productive uses. This standard story of the stock market was called into question by events in the late 1990s, when some observers believed that stock market overvaluation – or a bubble - led to overinvestment. Both the standard and overinvestment stories involve discount rates and, to differentiate between the two stories, this paper examines the discount rates used by firms in making their investment decisions.

We use a revealed preference approach that relies on the pattern of investment spending – combined with investment theory – to estimate the discount rates used by managers. The standard story predicts that firms with high stock prices and good investment opportunities should have discount rates that do not differ systematically from the risk-adjusted market rate. The overinvestment story predicts that firms with high stock prices and poor investment opportunities should have discount rates consistently below the market rate.

Based on a panel dataset of over 50,000 firm-year observations, we find support for both stories. The behavior of high stock price firms with good measured investment opportunities is best described by the standard story, while the overinvestment story provides the most appropriate interpretation of the behavior of high stock price firms with poor investment opportunities. Firms in this latter category accumulate between 15.1% and 45.2% too much capital. These estimates suggest that, even before they burst, bubbles adversely affect economic activity by misallocating capital.

JEL-Code: E440, E220, G300, E320.

Keywords: bubbles, investment, stock markets, real effects of financial markets, capital formation.

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> Are bubbles just a zero-sum game among financial market participants, or do they have real effects on investments, consumption, and employment? … This, in our view, is the most important question. … Many more such papers are needed.
>
> Bhattacharya and Yu, *Review of Financial Studies* (2008), pp. 8-9.

1. Introduction

Many economists believe that market prices do a good job of allocating resources. In particular, the stock market is seen as playing an important role in efficiently allocating capital to its most productive uses. The stock market price of a firm represents the expected present value of future dividends -- the "fundamental" price. Increases in the stock market price provide incentives for managers to issue equity and attract capital to their firms.

This standard view of the stock market was called into question by events in the late 1990s. Scores of commentators -- including many economists – claim that there was stock market overvaluation in the late 1990s. Moreover, there is a widespread belief that stock market overvaluation -- or a bubble -- led to overinvestment, especially in ".com" companies and Internet-related firms, such as those in telecommunications.[1] A bubble might affect investment if investors become unduly excited about particular firms and, in their excitement, they bid up the prices of these firms (Shiller, 2000, 2001; Shleifer, 2000). Overvalued shares lower the perceived cost of equity capital. If managers act on this lower perceived cost, they would issue new shares, lower the discount rate used in evaluating investment projects, and increase investment spending.[2]

The central core of the standard story of capital allocation involves rates of return and discount rates. Favorable shocks -- an increase in demand or a technical improvement – raise returns to capital for the fortunate firm (Cochrane, 2001; Fama, 1976). A firm earning high returns (relative to its cost of capital or discount rate) increases its capital stock until the return

[1] We are aware of the controversies that surround the use of the term "bubble" (see, for example, O'Hara, 2008). In this paper, bubble is merely a shorthand for stock market overvaluation.

[2] Baker (2009) reviews studies that have focused on the role of the supply of finance for investment spending.

on the marginal unit of capital again equals the discount rate. Absent externalities, capital is being allocated optimally.

The central core of the overinvestment story also involves rates of return and discount rates. A bubble lowers the discount rate, leading to higher investment. If managers use a discount rate below the market rate, they would invest too much, the rate of return on their investment would be too low, and capital would be misallocated.

This paper focuses on the central core of these two stories by examining the discount rates used by firms in making their investment decisions. One possible way to measure discount rates would be to survey managers. This approach has many advantages but, for our purposes, it has two key disadvantages. First, we cannot reach back in time to find out the discount rate used by managers at a time when their firm might have been overvalued. Second, there are potential issues of selection bias due to differential response rates across firms with different characteristics. Instead, we use a revealed preference approach that relies on the investment decisions of firms -- combined with investment theory -- to estimate the discount rates actually used by managers of U.S. firms.

To assess the potential role of bubbles, we focus on a class of firms – high-price firms -- that financial economists have identified as possibly overvalued. The high-price portfolio comprises firms with high stock market prices relative to a simple accounting measure of fundamentals. This class of firms is frequently referred to as "growth" firms. Such a label would be inconsistent with the perspective taken in this paper. Firms facing fundamental shocks and whose behavior is described by the standard story could be considered growth firms. However, this label is inappropriate for those firms whose high stock price is due to bubbles and whose behavior is described by the overinvestment story.

The standard story in economics holds that firms may enter the high-price portfolio as a result of favorable shocks that provide the firms with good investment opportunities and thus increase their stock market price. The overinvestment story claims that the high stock price of high-price firms is based on investor sentiment, not good investment opportunities. We therefore divide the firms in the high-price portfolio into those with good or poor investment opportunities. If the standard story applies to all high-price firms, firms with both good and poor investment opportunities should have discount rates equal to the market rate (suitably adjusted for risk).[3] If the misallocation story applies to all high-price firms, both sub-classes of firms should have discount rates that are lower than the market rate. Our econometric work suggests something in between. The estimated discount rate is above the market rate for firms with good investment opportunities. For firms with poor investment opportunities, the discount rate is below the market rate. The difference in discount rates (relative to risk-adjusted market rates) is economically and statistically significant. Thus the standard story describes high-price firms with good investment opportunities and the misallocation story high-price firms with poor investment opportunities.

We then undertake three robustness checks. First, the benchmark results are based on using demand shocks as a measure of investment opportunities. We examine cost shocks as an alternative way to identify recent news about investment opportunities. Firms with favorable cost shocks should have relatively good investment opportunities. Using cost shocks as a measure of investment opportunities, we confirm the benchmark results – the estimated discount rate for high-price firms with poor investment opportunities is below the market rate. It is significantly lower than the discount rate used by high-price firms with good investment opportunities. Second, insofar as investment opportunities may be difficult to measure, we also examine the discount rate wedge for high-price firms whose shareholders have long horizons. We would not expect firms described by these two characteristics to have a discount rate wedge that differs systematically from zero. This prediction is borne-out by the empirical results. Third, we take a different but complementary approach that evaluates a series of restricted econometric models in terms of J tests. These misspecified models are useful in evaluating the standard and overinvestment stories, and the test results are consistent with the above findings.

The paper proceeds as follows. Section 2 derives the Euler equation from a formal optimization problem that is the basis for the econometric analysis. Section 3 discusses the panel dataset (details are provided in the Appendix) and the summary statistics that describe various subsets of firms. Section 4 presents our benchmark results with this Euler equation and uncovers strong evidence for the empirical relevance of both the standard and overinvestment stories for appropriate subsets of firms. Section 5 contains several robustness checks. Section 6 concludes.

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[3] The discount rate will be above the market rate if finance constraints prevent firms from equating the discount rate to the market rate on a period-by-period basis.

2. Model

Our estimation strategy exploits the intertemporal pattern of investment spending to "reveal" the discount rate guiding investment decisions. The Euler investment equation has been a workhorse model in the investment literature and has been used by, among others, Shapiro (1986), Whited (1992), Hubbard and Kashyap (1992), and Chirinko and Schaller (2001, 2004) to study investment spending. Being a first-order condition for profit-maximization, the Euler equation is closely-tied to optimal firm behavior. Moreover, investment and discount rate variables enter explicitly (unlike, for example, the equally popular Brainard-Tobin Q equation), and thus it is straightforward to introduce a parameter representing the discount rate wedge.

The Euler equation that is the basis for our estimates can be obtained through informal and formal derivations.[4] The informal derivation begins with the net present value relation that links the stream of future benefits from an incremental capital project to its cost,

$$\sum_{j=0}^{\infty} R^{j+1} MPK_{t+j} = MIC_t , \tag{1}$$

where R is the real discount factor equal to $(1+r+\delta)^{-1}$ in the absence of bubbles (where r is the real risk-adjusted discount rate and δ is the economic rate of depreciation), MPK_{t+j} is the marginal product of capital associated with this incremental capital project, and MIC_t is the marginal investment cost. The latter term is composed of two parts, the purchase cost of the capital project relative to the price of output ($(p^I / p^Y)_t$) and the marginal adjustment cost (MAC_t). Equation (1) is based on the timing assumptions that revenues accrue at the end of the period, while investment costs are paid at the beginning of the period. It prove convenient to rewrite equation (1) as follows,

$$R\ MPK_t + \sum_{j=1}^{\infty} R^{j+1} MPK_{t+j} = MIC_t . \tag{2}$$

The companion net present value relation to equation (1) for period t+1 is written as follows,

$$R \sum_{j=0}^{\infty} R^{j+1} MPK_{t+1+j} = R\ MIC_{t+1} , \tag{3}$$

[4] The formal derivation can be found in any of the Euler equation studies cited above. The informal derivation was presented in Chirinko and Schaller (2004), which also contains an intuitive discussion of the Euler equation (p. 185).

where both sides of the equation have been multiplied by an extra R. Equation (3) can be rewritten as follows,

$$\sum_{j=1}^{\infty} R^{j+1} MPK_{t+j} = R\ MIC_{t+1}\,. \tag{4}$$

The difficulty with using any of these equations in estimation is that they contain an infinite number of future variables. This problem is overcome by a suitable transformation (akin to a Koyck transformation in distributed lag models). In this case, we subtract equation (4) from (2) and thus obtain the following Euler equation,

$$\begin{aligned} &R\ MPK_{t+j} - (MIC_t - R\ MIC_{t+1}) = 0, \\ &-(1+r+\delta)\ MIC_t + (MPK_t + MIC_{t+1}) = 0. \end{aligned} \tag{5}$$

The Euler equation in (5) can also be obtained as a first-order condition in a formal optimization problem. We assume that the firm chooses labor and capital inputs to maximize its market value. The firm is constrained by three technologies. The production technology ($F[L_t, K_t]$) relates output (Y_t) to the labor (L_t) and capital (K_t) inputs and to a stochastic technology shock. The adjustment cost technology ($G[I_t, K_t]$, where I_t is investment) affects the acquisition of capital (though not labor). Adjustment costs are valued by the price of foregone output, are affected by a stochastic shock, and are convex in investment. The latter is a critical assumption, as it forces the firm to consider its future plans when making current decisions. The accumulation technology determines the existing capital stock as a weighted sum of past investments, where the weights follow a declining exponential or geometric pattern. Moreover, the firm is a price-taker in its input market, though not necessarily in its output market. With the value maximization objective and these four constraints, optimal behavior for a forward-looking firm is determined by variational, optimal control, or dynamic programming methods.

In order to implement the Euler equation, we need to specify the MIC, MPK, and R variables. The MIC is specified as follows,

$$MIC_t = (p^I / p^Y)_t + MAC_t\ , \tag{6}$$

$$MAC_t = \alpha_0 + \alpha_1 (I/K)_t + \alpha_2 (I/K)_t^2\ , \tag{7}$$

where MAC_t is a second-order Taylor approximation to the adjustment cost function, $G[I\ , K_t]$.

The MPK is determined by an application of Euler's Theorem of Homogeneous Functions to the following relation between output and the production and adjustment cost technologies,

$$Y_t = F[L_t, K_t] - G[I_t, K_t], \tag{8}$$

to yield the following expression for the MPK,

$$MPK_t = \zeta\,(SALES/K)_t - (COST/K)_t + (I/K)_t\,MAC_t \tag{9}$$

where SALES is net nominal sales, COST is the nominal cost of goods sold and selling, general, and administrative expenses, and ζ is a parameter capturing the combined effects of imperfect competition and non-constant returns to scale in production. When the firm is a price-taker in its output market and $F[L_t, K_t]$ exhibits constant returns to scale, ζ equals 1. Deviations from these characteristics results in deviations of ζ from unity.

The discount factor, R, is generalized in two ways from the specification reported for equation (1). We recognize the possibility that our specification of the discount rate, r, may not be complete and may include a parameter, Θ, common to all firms. Of most importance to this study is the discount rate wedge, μ, that enters the specification only for subsets of firms and is multiplied by an indicator variable, Ω. This indicator variable varies by firm and over time and takes a value of 1 when firm *i* enters either the high-price PIO or high-price GIO portfolios, and leads to the following specification of the discount factor,

$$R_{i,t} = (1 + r_{i,t} + \delta_{i(s),t} + \Theta + \Omega_{i,t}^{PIO}\,\mu^{PIO} + \Omega_{i,t}^{GIO}\,\mu^{GIO})^{-1}\ , \tag{10}$$

where the firm (*i*), time (*t*), and sector (s) subscripts are explicit and *i(s)* indicates that the variable is available at the sector level for firm i.

The Euler equation is estimated by GMM with instruments that are lags of the variables appearing in the Euler equation,

$$W_{i,t} = \left\{ \begin{array}{l} (1-\tau_{t-1})(SALES_{i,t-1}/p_{i(s)}^{Y})/K_{i,t-2},\ \ (1-\tau_{t-1})(1+r_{i,t-1}+\delta_{i(s),t-1}), \\ (1-\tau_{t-1})(I_{i,t-1}/K_{i,t-2}),\ (1-\tau_{t-1})(I_{i,t-1}/K_{i,t-2})^2, \\ (1-z_{t-1}-u_{t-1})(p_{i(s),t-1}^{I}/p_{i(s),t-1}^{Y}),\ \Omega_{i,t-1}^{PIO},\ \Omega_{i,t-1}^{GIO} \end{array} \right\} \tag{11}$$

where τ_{t-1} is the corporate income tax rate, u_{t-1} is the investment tax credit rate, and z_{t-1} is the present value of depreciation allowances.

3. Dataset

We examine U.S. firms for two reasons. First, the United States has the most richly developed capital markets in the world and is therefore less likely to suffer from overvaluation and overinvestment. Second, the maximum amount of firm-level data is available for the United States. This latter factor is important to obtain a sufficient number of firms in the high-price portfolio, which contains only the top two deciles in a given year. This portfolio is further reduced by sorting by investment opportunities. Most of the empirical work is based on more than 50,000 firm-year observations. The panel data consists of a representative sample of U.S. publicly traded firms for the period 1980-2004. In fact, the sample approaches the universe of U.S. publicly traded firms. The primary data source is CompuStat with additional information obtained from CRSP and various sources of industry and aggregate data. Details about the dataset are contained in the Appendix.

We maximize the size of the dataset used in estimation in three ways. First, we use an unbalanced panel, and thus avoid the severe data restrictions imposed by a balanced panel. This choice has the further advantage of attenuating survivorship bias. Second, even in an unbalanced panel, some methods of constructing the replacement value of the capital stock require long strings of contiguous data to implement the perpetual inventory formula. We partly avoid this problem by tailoring our algorithm to preserve observations when there are gaps in the data and to use data that are more frequently available in CompuStat (e.g., when we find evidence of substantial acquisitions and divestitures, we use data on property, plant, and equipment in addition to the capital expenditure data). An additional problem posed by the perpetual inventory formula is its dependence on an initial or seed value of the capital stock drawn from financial statements. This initial value can be a particularly poor measure of capital's replacement cost that distorts the computed capital stock (K) until the impact of the initial value is largely depreciated. One solution to this problem is to compute the capital stock for many years before using these data in estimation, but this approach discards a substantial number of observations. As an alternative, we adopt the procedure discussed in detail in Chirinko and Schaller (2005) that computes an adjustment factor for the initial value taken from financial statements. Third, the Euler equation and the instruments we have chosen require only three years of contiguous data. All of the estimates reported below are based on sample sizes that exceed 50,000 firm-year observations.

The real risk-adjusted market discount rate (r_t) is constructed in several steps. We begin with a weighted-average of the nominal returns to debt and equity, where the weights vary by sector. The nominal return to debt is adjusted for the tax deductibility of interest payments. The nominal return to equity is based on the CAPM, and thus accounts for systematic risk. The nominal weighted-average is converted to a real return with an inflation adjustment that varies across sectors and over time.

The other variables used in this study are constructed as follows. Gross nominal investment is capital expenditures computed in a two-step procedure. We begin with the data on capital expenditures (CompuStat item 128). CompuStat does not always have reliable data for the changes to the capital stock associated with large acquisitions or divestitures, and we modify the algorithm of Chirinko, Fazzari, and Meyer (1999) to adjust the reported investment data. If the financial statement data indicate a substantial acquisition or divestiture, we use accounting identities to derive a more accurate measure of investment that replaces the data from item 128. Net Sales is CompuStat item 12. This nominal investment series is converted to a real investment series (I) by dividing by a sector specific price deflator. Sales growth (SG) is the annual growth rate in nominal net sales (S) divided by a sector specific price deflator. Variable costs is the sum of the Cost of Goods Sold (CompuStat item 41) and Selling, General, and Administrative Expense (CompuStat item 189; when this item is not reported, it is set to zero.) The depreciation rate is taken from the BEA, and is allowed to vary across industries and over time. The relative price of investment is the ratio of the price of investment to the price of output. These industry-specific, implicit price deflators are taken from the BEA; the relative price series is adjusted for corporate income taxes. New share issues (NSI) are measured as the ratio of the proceeds from equity issues relative to nominal investment spending. The marginal product of capital (MPK) is computed as described in equation (9).

We determine whether a firm is in the high-price portfolio in a given year using the Sales/Price ratio, the ratio of net nominal sales to the nominal value of common equity. The Sales/Price ratio has several key advantages: sales is a relatively straightforward accounting concept, rarely extremely small, and never negative.[5] Portfolios are formed by sorting all the firms for which the necessary data is available in a given year by the Sales/Price ratio. The two

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[5] The book/market ratio is also used in the literature, but it has many disadvantages. See, for example, the discussion of book/market in Lakonishok, Shleifer, and Vishny (1994).

deciles with the lowest Sales/Price ratio – equivalently, the highest stock price (relative to sales) -- in a given year are classified as high-price firms. The portfolio formation procedure allows a firm to be a high-price firm this year but not in a subsequent year. In fact, it is common for firms to move in and out of the high-price portfolio.

Firms that enter the high-price portfolio are further classified by investment opportunities (IO), which are measured by real sales growth over the prior three years. Firms with poor investment opportunities (PIO) or good investment opportunities (GIO) are those firms with sales growth in the bottom and top quartiles of high-price firms, respectively. Thus, in a given year, firms that are in the high-price, poor investment opportunity portfolio represent approximately 5% of the firms with serviceable data for that year.

When analyzing investment, we use the capital stock to control for size, which is frequently measured by the equity value of the firm (especially in finance research). In the current study concerned with stock market bubbles, this approach would be clearly inappropriate. Instead, we use the capital stock calculated using a standard perpetual inventory algorithm. The primary variable we analyze is the ratio of investment to the capital stock (I/K). There are a few extreme outliers for I/K. This is a common issue in panel data studies involving I/K. We address this issue by deleting the 1% tails of the I/K distribution.

Summary statistics are presented in three separate panels in Table 1. Panel A contains the Sales/Price ratio defining high-price portfolios and SG and Cost/Sales ratio defining firms with poor or good investment opportunities. Panel B contains variables describing these portfolios. As measured by the capital stock, the median high-price firm is less than half as large as the median firm in the sample. The median high-price firm expands more rapidly than the median firm; the respective I/K ratios are 0.135 and 0.087. Among the high-price firms, those with good investment opportunities (I/K equal to 0.151) are expanding at nearly twice the rate as firms with poor investment opportunities (I/K equal to 0.077). Consistent with this expansion, NSI (new share issues normalized by I) is very large for GIO firms. Moreover, high-price firms with poor investment opportunities have higher NSI than the median firm in the full sample (which includes all firms, not just those with high stock prices). The NSI is 0.381 for PIO firms, compared with 0.187 for the median firm. This active participation in equity markets by PIO firms resonates with the possibility that they are exploiting the availability of cheap equity finance due to a bubble in their share price.

Table 1 Summary Statistics

A. Variables Determining Portfolios

	N	Mean	25%	50%	75%	Std Dev.	Skewness	Kurtosis
Sales/Price								
All	55021	77.777	0.691	1.477	3.086	6459.91	117.120	15191.56
High-Price	6019	0.340	0.137	0.249	0.403	0.770	42.373	2332.31
High-Price & Poor IO	1162	0.385	0.120	0.252	0.416	1.434	28.829	917.257
High-Price & Good IO	962	0.322	0.097	0.213	0.398	0.448	7.010	87.483
SG								
All	55021	0.137	-0.046	0.061	0.199	1.241	71.092	6734.88
High-Price	6019	0.522	-0.0001	0.175	0.444	3.606	26.090	849.660
High-Price & Poor IO	1162	0.958	-0.059	0.118	0.482	6.678	16.274	312.515
High-Price & Good IO	962	0.663	-0.009	0.261	0.609	3.577	20.900	528.662
Cost/Sales								
All	55021	0.988	0.842	0.903	0.959	3.606	199.842	43914.78
High-Price	6019	1.574	0.707	0.841	1.216	10.862	66.700	4863.65
High-Price & Poor IO	1162	2.617	0.751	0.977	1.599	23.962	31.962	1060.24
High-Price & Good IO	962	2.119	0.827	1.083	1.760	4.275	8.943	100.892

B. Variables Describing Portfolios

	N	Mean	25%	50%	75%	Std Dev.	Skewness	Kurtosis
K								
All	55021	1463.20	16.293	78.871	427.381	12632.77	86.369	12394.70
High-Price	6019	789.291	7.265	35.520	276.902	3049.90	9.983	160.613
High-Price & Poor IO	1162	648.392	3.944	17.817	183.375	3073.55	12.049	200.205
High-Price & Good IO	962	269.783	4.314	14.148	53.328	1428.99	8.919	91.768
I								
All	55021	122.878	1.086	6.561	37.890	780.978	32.571	1757.34
High-Price	6019	104.235	0.636	4.546	34.066	493.473	14.032	279.405
High-Price & Poor IO	1162	53.035	0.219	1.270	12.633	207.757	6.926	58.972
High-Price & Good IO	962	41.806	0.311	1.529	9.407	217.249	9.679	115.579
I/K								
All	55021	0.130	0.041	0.087	0.165	0.140	2.334	6.834
High-Price	6019	0.199	0.052	0.135	0.283	0.196	1.461	1.800
High-Price & Poor IO	1162	0.122	0.030	0.077	0.157	0.141	2.286	6.642
High-Price & Good IO	962	0.223	0.055	0.151	0.338	0.215	1.210	0.792
NSI								
All	48725	15.425	0.000	0.187	2.845	118.503	37.817	2388.67
High-Price	4969	26.791	0.057	1.195	8.310	150.421	20.263	566.958
High-Price & Poor IO	978	19.506	0.000	0.381	4.270	178.792	21.783	535.091
High-Price & Good IO	771	27.634	0.188	1.592	6.523	173.688	15.414	305.096

Table 1 Summary Statistics (continued)

C. Other Variables Entering The Estimating Equation

	N	Mean	25%	50%	75%	Std Dev.	Skewness	Kurtosis
MPK								
All	55021	0.870	0.0405	0.231	0.760	2.126	4.686	28.095
High-Price	6019	1.749	0.028	0.509	2.020	3.474	2.621	8.151
High-Price & Poor IO	1162	0.519	-0.051	0.092	0.623	2.095	4.092	29.637
High-Price & Good IO	962	1.857	-0.112	0.310	2.529	3.980	2.124	5.087
r								
All	55021	0.120	0.093	0.120	0.146	0.037	0.429	2.829
High-Price	6019	0.116	0.085	0.111	0.146	0.047	1.277	5.274
High-Price & Poor IO	1162	0.121	0.085	0.112	0.148	0.056	1.695	5.526
High-Price & Good IO	962	0.116	0.088	0.113	0.139	0.043	1.503	6.882
p^I / p^Y								
All	55021	1.032	0.871	1.000	1.123	0.287	1.718	5.704
High-Price	6019	1.035	0.807	1.000	1.147	0.331	1.541	3.242
High-Price & Poor IO	1162	0.994	0.767	1.000	1.121	0.298	1.349	3.772
High-Price & Good IO	962	1.050	0.767	0.998	1.156	0.379	1.431	2.066

Notes

The variables appearing in the tables are computed for the period 1980 to 2004 and are defined as follows: Sales/Price is the ratio of nominal sales to nominal common equity value; SG is real sales growth; Cost/Sales is the ratio of nominal costs of goods sold to nominal sales; K is the real replacement cost of the stock of capital in property, plant, and equipment in millions of 1996 dollars; I is real investment in property, plant, and equipment in millions of 1996 dollars; NSI is the ratio of new share issues to nominal investment spending; MPK is the marginal product of capital; r is the real risk-adjusted market discount rate; p^I/p^Y is the ratio of the price of investment goods to the price of output. Details concerning the definitions, construction, and sources of the data are discussed in Section 3 and the Appendix.

Panel C contains variables other than I/K entering the estimating equation. Consistent with the robust investment opportunities available to high-price GIO firms, their median MPK of 0.310 is much larger than that for the median high-price PIO firm (0.092) or the median firm (0.231). The values of the remaining variables – the real risk-adjusted market rate and the relative price of investment goods – are similar across subsets of firms.[6] Taken together, these results suggest that investment opportunities and MPK's are the key differences between high-price PIO and GIO firms, and hence will play an important role for our estimates of the discount rate wedge.

4. Benchmark Empirical Results

This section presents estimates of the discount rate wedge based on the Euler equation (5) and the investment behavior of high-price firms at the time of portfolio formation. To attempt to differentiate between the standard and overinvestment stories, the high-price portfolio is divided by the investment opportunities available to firms. If the standard story applies to all firms in the high-price portfolio, firms with either PIO or GIO should use discount rates that do not differ systematically from their risk-adjusted market rates. However, if the overinvestment story is relevant for a subset of firms in the high-price portfolio, their actual discount rate should be below their risk-adjusted market rate. This situation is most likely to occur for high-price PIO firms. Thus, the discount rate wedge, represented by μ and defined as the difference between the actual discount rate used by the firm and its risk-adjusted market rate, will allow us to discriminate between the standard and overinvestment stories.

We use the Euler equation to estimate the discount rate wedge for the high-price firms with poor (μ^{PIO}) and good (μ^{GIO}) investment opportunities, respectively. In the first column of Table 2, μ^{PIO} is -0.195, a result that is both economically and statistically significant and consistent with the overinvestment story. By contrast, μ^{GIO} is very close to zero, which is consistent with the standard story. The Wald test reported in the second row evaluates the hypothesis that $\mu^{PIO} = \mu^{GIO}$ and is computed by the delta method. The null hypothesis of equal discount rate wedges is rejected with a p-value of 0.021. These results provide strong evidence for the importance of differentiating between classes of firms and for the empirical relevance of both the standard and overinvestment stories.

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[6] The median and mean value of r is approximately 0.120. This figure is consistent with survey evidence. Poterba and Summers (1995) report estimates of the average real hurdle rate indicating that r is 0.122. This estimate has been confirmed in a study by Meier and Tarhan (2007), who report a comparable financial cost of capital of between 0.119 and 0.141.

Table 2 Estimates of the Discount Rate Wedge – Baseline Model

	High-Price Firms		
	Investment opportunities measured by demand shocks	Investment opportunities measured by Cost shocks	Long Horizons
	(1)	(2)	(3)
μ^{PIO}	-0.195** (0.097)	-0.224* (0.133)	-------- --------
μ^{GIO}	-0.004 (0.060)	0.051 (0.059)	-------- --------
μ^{LH}	-------- --------	-------- --------	0.055 (0.046)
Wald	5.337** [0.021]	4.202** [0.040]	1.431 [0.232]
ζ	0.931*** (0.013)	0.939*** (0.012)	0.919*** (0.016)
α_0	0.593 (0.648)	0.365 (0.599)	1.009 (0.815)
α_1	35.132*** (10.713)	30.609*** (3.695)	45.695*** (15.424)
$G_I[I_t, K_t : \alpha_0, \alpha_1]$	3.657	3.016	5.023
$G_{II}[I_t, K_t : \alpha_0, \alpha_1]$	0.445	0.366	0.589
J	0.685 [0.408]	1.241 [0.265]	0.087 [0.926]
N	55,021	53,038	55,486

Table 2 Estimates of the Discount Rate Wedge – Baseline Model (continued)

Notes

GMM estimates are based on equation (5) and on panel data for the period 1980 to 2004. Firms are placed in the high-price portfolio if their ratio of equity value to sales is in the highest two deciles. The μ^{PIO}, μ^{GIO}, and μ^{LH} parameters are the discount rate wedges for high-price firms with poor investment opportunities (PIO), with good investment opportunities (GIO), and with long horizons (LH), respectively. Investment opportunities are measured in column (1) by sales growth, defined as real sales growth over the prior three years, and in column (2) by the cost ratio, defined as the ratio of nominal costs to nominal sales over the previous three years. Firms with poor investment opportunities are those firms in the high-price portfolio with sales growth in the bottom quartile or the cost ratio in the top quartile. The portfolio for good investment opportunities is formed in a similar way for the top quartile for sales growth and the bottom quartile for the cost ratio. Horizons are measured by share turnover, defined as the mean (over the year) of the daily ratio of the volume of shares traded to shares outstanding at the end of the day. Firms with long horizons are those with share turnover in the prior year above the median for all observations in the prior year. All portfolios are formed based on beginning-of-period values and are reevaluated every year. The Wald statistic is computed by the delta method and evaluates the hypothesis that $\mu^{PIO} = \mu^{GIO}$ in columns (1) and (2) and the hypothesis that $\mu^{LH} = 0$ in column (3); p-values are in brackets. The ζ parameter captures deviations from constant returns to scale or perfect competition; a value of ζ less than unity is consistent with either decreasing returns to scale regardless of the degree of competition in the output market or increasing returns to scale and a sufficient degree of imperfect competition to force the marginal return to capital below its average return. In either case, the firm is earning positive economic rents. The α parameters are from the marginal adjustment cost function defined in equation (7). The $G_I[I_t, K_t : \alpha_0, \alpha_1] = MAC_t$ statistic is the marginal adjustment cost function; the $G_{II}[I_t, K_t : \alpha_0, \alpha_1]$ statistic is the curvature of the adjustment cost function. Both adjustment cost statistics depend on the estimated α parameters and are evaluated at the median values I_t and K_t. The J statistic is the Hansen-Sargan statistic for overidentification; p-values are in brackets. N is the number of firm/year observations. The instruments are discussed in Section 2. Details concerning the definitions, construction, and sources of the data are discussed in Section 3 and the Appendix. Standard errors are in parentheses, and ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Three additional results presented in column (1) are worth noting. First, the ζ parameter, which captures deviations from constant returns to scale or perfect competition, is less than one. While the difference from unity is statistically significant, it would not appear to be economically important. Second, marginal adjustment costs are positive and increasing, and thus the adjustment cost function is convex. This property is required by the optimization problem presented in Section 2 that underlies the Euler equation. Third, the Hansen-Sargan J test evaluating the overidentifying restrictions fails to reject the model, thus providing some assurance of the reasonableness of our empirical specification.

The point estimate of $\mu^{PIO} = -0.195$ indicates a substantial misallocation of capital. In order to draw the implications of bubbles for capital formation, we need to assess the impact of μ^{PIO} on the incentive to accumulate capital and then the impact of this enhanced incentive on capital accumulation. Recall that our estimates of μ^{PIO} and μ^{GIO} apply to the lowest and highest quartile of high-price firms, respectively, sorted by investment opportunities. We assume that this wedge would decline evenly between these two extremes, and hence the average value for the change in the discount rate wedge for all high-price firms is $\Delta\mu = -0.100$. Lowering the discount rate by -0.100 leads to a 37.7% decline in the user cost of capital (see the Appendix for the computations). The impact of these enhanced incentives on capital formation depends on the degree to which capital substitutes for other factors in the production function. Estimates of this elasticity of substitution have varied widely from 0.40 (Chirinko, Fazzari, and Mayer, forthcoming) to 1.00 (the value implied by a Cobb-Douglas production function) to 1.20 (Schaller, 2006). Given this range of elasticities, high-price firms accumulate between 15.1% and 45.2% too much capital. While high-price firms comprise 20% of the sample, their mean capital stock is approximately half as large as that for the mean firm (see Table 1.B.). Taken together, these figures roughly imply a reduction of 1.5% to 4.5% of the capital stock for publicly traded firms. It takes a substantial period of time for these excesses to be reversed by the depreciation of capital (though the adjustment process could be accelerated by a reduction in planned investment spending). Five years after a bubble, nearly one-half of the misallocated capital would remain. The effects of bubbles on misallocating capital are substantial and may be long-lasting.

5. Robustness Checks

This section presents a series of robustness checks on the Euler equation and the core result that both the standard and overinvestment stories are empirically relevant.

5.1. Cost Shocks

The results discussed so far have been based on demand shocks as a measure of investment opportunities. In this sub-section, we turn instead to cost shocks. Specifically, we use low (or perhaps negative) recent growth in the Cost/Sales ratio to identify firms with good investment opportunities. Favorable cost shock observations are defined as those with a change in the ratio of nominal costs to nominal sales over the previous three years in the bottom quartile.

The results based on cost shocks are presented the column (2) of Table 2, and the results strongly parallel those with demand shocks. In particular, μ^{PIO} is negative and statistically and economically significant, and μ^{GIO} is not statistically far from zero. The difference between these two discount rate wedges is somewhat smaller than in column 1; nonetheless, the Wald statistic confirms that this difference is statistically significant.

5.2. Long Horizons

Stein (1996) develops a theoretical model in which a bubble induces a firm to use a discount rate lower than the risk-adjusted rate if the manager has short horizons or the financing constraint is binding. In the former case, a bubble presents short-horizon managers with an opportunity in the form of cheap equity without the attending costs when a bubble becomes widely known. In the latter case, a bubble presents financially-constrained managers with an opportunity to relax a binding constraint. According to the Stein model, the discount rates of firms with long horizons and without a financing constraint at the time of portfolio formation will be unaffected by a bubble.

To test this latter prediction, we need to identify a class of firms that is financially unconstrained and whose managers have short horizons. High-price firms are unlikely to have binding finance constraints. We identify firms with short horizons on the basis of their share turnover. The intuition is simple. Investors care about the performance of the firm until when they sell their shares. When turnover is high -- and the expected duration of share ownership is therefore low -- the median shareholder will tend to care less about the firm's performance in the more distant future. As a result, managers may behave as if they have a short horizon. Horizons are measured by share turnover, defined as the mean (over the year) of the daily ratio of the volume of shares traded to shares outstanding at the end of the day. Firms with long horizons are those with share turnover in the prior year above the median for all observations in the prior year.

Euler equation estimates of the discount rate wedge for firms with high-prices and low share turnover are presented in column (3) of Table 2. The model delivers sensible results for the adjustment cost function and the J statistic. More importantly, these results document that the prediction of the Stein model is consistent with the data. The estimated discount rate wedge for high-price firms with long horizons is small and statistically insignificant.

5.3. Restricted Models

The results presented in Table 2 have defined discount rate wedges in order to evaluate hypotheses suggested by the theory. This sub-section takes a different but complementary approach and estimates a series of restricted models. These misspecified models are useful in assessing the standard and overinvestment stories and are evaluated by the J statistic.

Table 3 contains estimates of several restricted models. We begin with our benchmark model presented in column (1) of Table 2 (with investment opportunities measured by demand shocks) and constrain the discount rate wedge for firms with good investment opportunities (μ^{GIO}) equal to zero. The estimates are extremely similar to those for the benchmark model; for example, the coefficient on μ^{PIO} changes by less than two percent. Specification issues arise, however, when μ^{PIO} is constrained to zero in column (2). In this case, the J statistic rises sharply and has a p-value of 0.020 that indicates model misspecification. Given these results, it is not surprising that when both discount rate wedges are constrained to zero, the J statistic indicates that the model remains misspecified.

These results are confirmed in columns (4) through (6) when investment opportunities are measured by cost shocks. The only difference is that when μ^{PIO} is constrained to zero in column (5), the p-value of 0.105 is slightly above the conventional cutoff of 0.100.

Taken together, the results in Table 3 confirm the findings that both the standard and overinvestment stories describe subsets of high-price firms.

6. Conclusions

This paper considers the possibility that the stock market occasionally overvalues firm and these bubbles lead to overinvestment. If stock prices rise above fundamental values (a possibility suggested by much recent academic literature), firms would have access to a relatively cheap source of finance that results in an increase in investment. For these overvalued

Table 3 Estimates of the Discount Rate Wedge – Restricted Models

	Investment opportunities measured by demand shocks			Investment opportunities measured by cost shocks		
	$\mu^{GIO}=0$	$\mu^{PIO}=0$	$\mu^{GIO}=0$ $\mu^{PIO}=0$	$\mu^{GIO}=0$	$\mu^{PIO}=0$	$\mu^{GIO}=0$ $\mu^{PIO}=0$
	(1)	(2)	(3)	(4)	(5)	(6)
μ^{PIO}	-0.192** (0.082)	0	0	-0.270** (0.137)	0	0
μ^{GIO}	0	0.003 (0.058)	0	0	0.041 (0.058)	0
Wald	5.459** [0.019]	0.003 [0.958]	-------- --------	3.865** [0.049]	0.504 [0.478]	-------- --------
ζ	0.931*** (0.011)	0.923*** (0.014)	0.924*** (0.011)	0.943*** (0.009)	0.925*** (0.015)	0.930*** (0.011)
α_0	0.628 (0.440)	0.673 (0.703)	0.645 (0.468)	0.079** (0.040)	1.034 (0.739)	0.717 (0.477)
α_1	35.712*** (7.295)	38.513*** (11.528)	38.058*** (7.681)	26.005*** (6.505)	42.294*** (11.663)	37.245*** (7.508)
$G_I[I_t, K_t : \alpha_0, \alpha_1]$	3.743	4.032	3.964	2.331	4.696	3.942
$G_{II}[I_t, K_t : \alpha_0, \alpha_1]$	0.453	0.488	0.483	0.311	0.506	0.446
J	0.620 [0.733]	7.839** [0.020]	7.861** [0.049]	2.620 [0.270]	4.505 [0.105]	6.859* [0.077]
N	55,021	55,021	55,021	53,038	53,038	53,038

Notes
See the notes to Table 2.

firms, the added investment represents a misallocation of capital, and thus financial market bubbles have real effects. This overinvestment story contrasts with the standard story of stock markets efficiently allocating capital to its best uses.

This paper presents empirical evidence to differentiate between the standard and overinvestment stories. Our primary tests rely on the discount rates guiding investment decisions. The standard story predicts that high-price firms with good investment opportunities should have discount rates that do not differ systematically from the risk-adjusted market rate. (The Stein model also predicts that the pattern of discount rates used by firms that are financially unconstrained and owned by shareholders with long horizons should be similar to the standard story.) The misallocation story predicts that high-price firms with poor investment opportunities should have discount rates consistently below the market rate. The discount rates guiding investment decisions are unobservable but are revealed by examining the intertemporal pattern of investment implied by the Euler equation for investment and variation in panel data.

Based on a panel dataset of over 50,000 firm-year observations, we find support for both stories. The investment behavior of high-price firms with good investment opportunities is consistent with the standard story. However, the overinvestment story best describes the behavior of high-price firms with poor investment opportunities. Our estimates indicate that high-price firms (with both poor and good investment opportunities) accumulate between 15.1% and 45.2% too much capital as a result of a stock market bubble. Even before they burst, bubbles adversely affect economic activity by misallocating capital. The overinvestment story is further supported by a series of robustness checks on the Euler equation. Our overall conclusion is that, for an important subset of firms, stock market bubbles lead to capital misallocation.

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Appendix

A.1. Construction of High-Price and Low-Price Portfolios

We construct the high-price and low-price portfolios using the Sales/Price ratio. The Sales/Price ratio is Net Sales (CompuStat item 12) divided by Common Shares Outstanding (CompuStat item 25) times Price – Fiscal Year – Close (CompuStat item 199). Observations with missing or non-positive values for the Sales/Price ratio are dropped. The remaining observations for a given year are sorted into deciles. The top two deciles are classified as low-price firms (i.e., firms with low stock market prices relative to the Sales/Price ratio). The bottom two deciles are classified as high-price firms (i.e., firms with high stock market prices), and the remaining deciles are classified as typical.

A.2. Capital Stock and Investment

For the first observation for firm f, the capital stock is based on the net plant (NPLANT), the nominal book value of net property, plant, and equipment (CompuStat item 8). To convert this to real terms, we divide by the sector-specific price index for investment (p^I). Since book value is not adjusted for changes in the value of capital goods purchased in the past, we adjust the initial capital stock using a sector-specific adjustment factor (AF):

$$K_{i,t_0^i} = \frac{NPLANT_{i,t_0^i}}{p^I_{s,t_0^i}} AF_s \qquad \text{(A1)}$$

where s is a sector index (for firm i's sector) and t_0^i is the year of the first observation for firm i.

Failure to adjust book value affects the initial value of the capital stock but has a geometrically decreasing impact on the measured capital stock over time. After 15 years, the initial value effect is negligible. We use this fact to construct the adjustment factor for the initial value of the capital stock. For sector s, AF is (the ratio of current cost net stock of private fixed assets by industry to the historical-cost net stock of private fixed assets by industry) times (the ratio of the mean unadjusted capital stock for firms of age 15 or greater to the mean of what the unadjusted capital stock would have been measured as, if t equaled t_0^i (i.e., if the current year were the firm's first year in the sample)). In effect, AF is the ratio of the true capital stock to the unadjusted initial value.

For subsequent observations, a standard perpetual inventory method is used to construct the capital stock,

$$K_{i,t+1} = (1-\delta_{s,t})K_{i,t} + \frac{KCHG_{i,t+1}}{p^I_{s,t+1}} \qquad \text{(A2)}$$

where δ is the depreciation rate and KCHG is gross additions to the firm's capital stock. The firm reports the additions in nominal terms, so we divide by p^I to convert to real terms.

In the standard case, KCHG is gross investment (I), which is capital expenditures in the firm's financial statements (CompuStat item 128). CompuStat does not always have reliable data for the additions to the capital stock associated with large acquisitions. We use a modified version of the algorithm of Chirinko, Fazzari, and Meyer (1999) to adjust KCHG for acquisitions and divestitures. In the case of a substantial acquisition, we can use accounting identities to derive a more accurate measure of the additions to the capital stock:

$$DGPLANT_{i,t} = I_{i,t} + ACQUIS_{i,t} - RETIRE_{i,t} \tag{A3}$$

where DGPLANT is the change in GPLANT from the end of year t-1 to the end of year t and GPLANT is gross property, plant, and equipment (CompuStat item 7), ACQUIS is acquisitions, and RETIRE is retirements of capital stock (CompuStat item 184). (When data on RETIRE is missing, we assume that the reason is that firms do not report any retirements in their financial statements, and we therefore assign a value of 0 to RETIRE for these observations.) We use the following screen to identify cases where there has been a substantial acquisition. If

$$\frac{DGPLANT_{i,t} - I_{i,t}}{GPLANT_{i,t-1}} > 0.1 \tag{A4}$$

then we calculate the gross change in the capital stock as

$$KCHG_{i,t} = DGPLANT_{i,t} + RETIRE_{i,t} \tag{A5}$$

We also account for substantial divestitures, using the following screen. If

$$\frac{DGPLANT_{i,t} + RETIRE_{i,t}}{GPLANT_{i,t-1}} < -0.1 \tag{A6}$$

we calculate the change in the capital stock as

$$KCHG_{i,t} = DNPLANT_{i,t} + \delta K_{i,t-1} p^I_{s,t} \tag{A7}$$

where DNPLANT is the change in NPLANT (as defined above). (To see this result, start with the perpetual inventory equation, $K_{i,t} = I_{i,t} + (1-\delta)K_{i,t-1} \rightarrow K_{i,t} - K_{i,t-1} + \delta K_{i,t-1} = I_{i,t}$. Now, put the previous equation in nominal terms, $[K_{i,t} - K_{i,t-1}]p^I_s + \delta K_{i,t-1} p^I_s = I_{i,t} p^I_s \rightarrow$ $DNPLANT_{i,t} + \delta K_{i,t-1} p^I_{s,t} = I_{i,t} p^I_{s,t} = KCHG_{i,t}$.) Because NPLANT in the firm's financial statements will deduct depreciation (as well as accounting for the divestiture), depreciation must be added to KCHG to avoid deducting depreciation twice.

If *GPLANT* is missing (or equal to zero) or *DGPLANT* is missing, it is not feasible to use these screens, and we set KCHG equal to I.

In some cases, there is a data gap for a particular firm. In this case, we treat the first new observation for that firm in the same way as we would if it were the initial observation. This avoids any potential sample selection bias that would result from dropping firms with gaps in their data.

We construct sector-specific, time-varying depreciation rates using data from the BEA. Specifically,

$$\delta_{s,t} = \frac{D\$_{s,1996}\, DQUANT_{s,t}}{K\$_{s,1996}\, KQUANT_{s,t}} \tag{A8}$$

where D$ is current-cost depreciation of private fixed assets by sector (BEA, Table 3.4ES), DQUANT is the chain-type quantity index of depreciation of private fixed assets by sector (BEA, Table 3.5ES), K$ is the current cost net stock of private fixed assets by sector (as defined above), and KQUANT is the chain-type quantity index of the net stock of private fixed assets by sector (BEA, Table 3.2ES).

We construct the sector-specific price index for investment using BEA data:

$$p^{I}_{s,t} = \frac{100(I\$_{s,t} / I\$_{s,1996})}{IQUANT_{s,t}} \tag{A9}$$

where I$ is historical-cost investment in private fixed assets by sector (BEA, Table 3.7ES) and IQUANT is the chain-type quantity index of investment in private fixed assets by sector (BEA, Table 3.8ES).

A.3. Tax-Adjusted Relative Price of Investment Goods

We define the tax-adjusted relative price of investment goods as follows,

$$p^{I}_{s,t} = \left(\frac{1 - z_t - u_t}{1 - \tau_t}\right)\frac{p^{I@}_{s,t}}{p^{Y}_{s,t}} \tag{A10}$$

where z is the present value of depreciation allowances, u is the investment tax credit rate, τ is the corporate tax rate, $p^{I@}$ is the price of investment goods, and p^{Y} is the price of output. Where variables are available at a monthly or quarterly frequency, we take the average for the calendar year. The corporate tax rate is the U.S. federal tax rate on corporate income. The present value of depreciation allowances – for non-residential equipment and structures, respectively – were provided by Dale Jorgenson. To calculate z, we took the weighted sum of Jorgenson's z's for equipment and structures, where the weights are the share of equipment investment and the share of structures investment (for a given year) in nominal gross private non-residential investment in fixed assets from the Bureau of Economic Analysis (from table 1IHI, where equipment investment is referred to as equipment and software). Because the investment tax credit applies only to equipment, u=0 for structures, we multiply the statutory ITC rate for each year by the ratio of equipment investment to the sum of structures and equipment investment for that year.

The corporate tax rates were provided directly by the Treasury Department, and investment tax credit rates are drawn from Pechman (1987, p.160-161). The sector-specific price index for output is the implicit price deflator for Gross Domestic Product by industry produced by the BEA, normalized to 1 in 1996.

A.4. The Real Risk-Adjusted Market Discount Rate

The real, risk-adjusted market discount rate is defined as follows,

$$r_{i,t} = ((1+r_{i,t}^{NOM}) / (1+\pi_t^e)) - 1.0. \tag{A11}$$

The equity risk premium is calculated using CAPM. The components of $r_{i,t}$ are defined and constructed as follows,

$r_{i,t}^{NOM}$	=	Nominal, short-term, risk-adjusted cost of capital,
	=	$\lambda_s (1-\tau_t)\ r_t^{NOM,DEBT} + (1-\lambda_s)\ r_{s,t}^{NOM,EQUITY}$,
$r_t^{NOM,DEBT}$	=	Nominal corporate bond rate (Moody's Seasoned Baa Corporate Bond Yield),
$r_{s,t}^{NOM,EQUITY}$	=	Nominal, short-term, risk-adjusted cost of equity capital for firms in sector s,
	=	$r_t^{NOM,F} + \sigma_s$,
$r_t^{NOM,F}$	=	Nominal, one-year, risk-free rate (One-Year Treasury Constant Maturity Rate),
$\pi_{s,t}^e$	=	Sector-specific capital goods price inflation rate from t to t+1. Sector-specific data was not yet available for 2002 at the time of data construction, so the inflation rate for nonresidential fixed investment was used for $\pi_{s,t}^e$ for 2001,
σ_s	=	Equity risk premium,
τ_t	=	Marginal rate of corporate income taxation,
λ_s	=	Sector-specific leverage ratio calculated as the mean of book debt for the sector divided by the mean of (book debt + book equity) for the sector.

Under the CAPM,

$$\sigma_s = \beta_s (\phi^{EQUITY} - \phi^F), \tag{A12}$$

where

β_s	=	CAPM β for sector s
ϕ^{EQUITY}	=	Total return on equities from 1950-2001. The source is the value-weighted CRSP index (including dividends)
ϕ^F	=	Total return on risk-free Treasury bills from 1950-2001. The source is the FRED database, specifically the series for 1-Year Treasury Constant Maturity Rate

A.5. Bubbles and Overinvestment

This section provides the details underlying the calculations reported in Section IV. Three steps are required to translate the discount rate wedge of $\mu^{PIO} = -0.195$ into the amount of misallocated capital for high-price firms.

First, we translate the estimate of the discount rate wedgesthat apply to the lowest and highest quartile (measured by investment opportunities) of high-price firms to all high-price firms. We know that the discount rate wedges are $\mu^{PIO} = -0.195$ and $\mu^{GIO} = -0.004$ for the lowest and highest quartile of high-price firms, respectively. We assume that this wedge declines evenly between these two extremes, and hence the discount rate wedges for all four quartiles are -0.195, -0.131, -0.068, and -0.004. (This procedure is numerically equivalent to averaging the estimates of μ^{PIO} and μ^{GIO}.) The average value for the change in the discount rate wedge for all high-price firms is $\Delta\mu = -0.100$.

Second, the user cost of capital can be represented as follows,

$$UC = (r + \mu + \delta) * RP * TAX, \tag{A13}$$

where r is the real, risk-adjusted discount rate discussed above, μ is the discount rate wedge, δ is the economic rate of capital depreciation, RP is the relative price of investment goods, and TAX represents a collection of tax variables (income tax and investment credit rates; value of tax depreciation). The percentage change in the user cost evaluated at $\mu = 0$ is computed as follows,

$$\%\Delta UC = \Delta\mu / (r + \delta). \tag{A14}$$

Based on the dataset, the mean value of r is 0.120 and δ is 0.145. Based on these figures, the percentage change in the user cost equals,

$$\%\Delta UC = \Delta\mu / (r + \delta) = -0.100 / (0.120 + 0.145) = -0.377. \tag{A15}$$

Third, per the discussion in Section 4, we assume that the elasticity of substitution between capital and other factors (σ) is between 0.40 and 1.20. Thus, the lower and upper bounds of the percentage change in the capital stock is computed according to this formula,

$$\%\Delta K = -\sigma * (\%\Delta UC) = \{0.151,\ 0.452\}\ . \tag{A16}$$