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Dectecting speculative bubbles in stock prices: A new approach and some evidence for the US

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Detecting Speculative Bubbles in Stock Prices: A New Approach and Some Evidence for the US

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Detecting Speculative Bubbles in Stock Prices:
A New Approach and Some Evidence for the US

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Abstract

A large part of the current debate on US stock price behavior concentrates on the question of whether stock prices are driven by fundamentals or by non-fundamental factors. In this paper we put forward the hypothesis that a present value model with time-varying expected returns provides an empirically valid description of US stock price behavior in the long-run, while short-run deviations of actual share prices from present value prices are driven by non-fundamental factors like speculative bubbles and/or noise trading behavior. Our empirical findings for the US stock market covering the 1871:1 – 2000:12 period provide strong and robust support for the hypothesis that in the short-run US stock prices exhibit non-fundamental run-ups followed by crashes, while in the long-run US share prices adhere to fundamentals.

Keywords: Present Value Model, US Stock Prices, Asymmetric Adjustment, Cointegration

JEL Classification: G12, E44, C32

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1. Introduction

One of the most actively investigated economic phenomena of the last decades has been the behavior of aggregate US stock prices. The stock market surge in the closing years of the twentieth century renewed the debate on the influence of fundamentally versus non-fundamentally justified stock price movements.[1] According to the standard present value model stock prices are fundamentally determined by the discounted value of its expected future dividends, which in turn derive their value from future expected earnings (e.g., see Campbell, Lo and MacKinlay, 1997; Cochrane, 2001). Non-fundamental stock price increases and crashes which follow stock prices that reach high levels can be integrated into present value models by dropping the transversality condition. In addition, such outcomes can be theoretically justified by stochastic speculative bubbles (Blanchard and Watson, 1982; West, 1987; Evans, 1991). Noise trader models along the lines of Kirman (1991, 1993) and Shleifer (2000) also provide a theoretical rational for this kind of non-fundamental stock price behavior.

Empirical analyses on the validity of present value models have been extensively conducted in the cointegration framework by relying on two approaches. First, based on a present value model, under the assumption of a constant discount rate, it can be shown (Campbell and Shiller, 1987) that the levels of stock prices and dividends are theoretically cointegrated if stock prices and dividends follow integrated processes of order one and the transversality condition holds. Second, assuming a time-varying discount rate instead of a constant one, the log difference between dividends and prices follows a stationary process if the present value model is valid (Campbell and Shiller, 1988a, b).

The available empirical evidence in the finance literature on both types of models, however, is mixed. The widely quoted studies of Campbell and Shiller (1987) and Diba and Grossman (1988) contain ambiguous findings for the US stock market for the 1871 – 1986 period, depending on the implemented test approach and its specification. The evidence for the log dividend-price ratio is equally ambiguous. For example, Froot and Obstfeld (1991), using US data for the 1900 – 1988 period, found mixed empirical evidence depending on the chosen deterministic components in the Dickey-Fuller (1981) regression. More recently, Lamont (1998) provides evidence in favor of a unit root in the log dividend-price ratio relying on US quarterly data 1947:1 – 1994:4 and standard Dickey-Fuller tests. However, bivariate Horvath-Watson (1995) tests produce strong evidence in favor of a cointegrating relationship between dividends and stock prices. Balke and Wohar (2001) are also unable to reject the null hypothesis of a unit root applying Dickey-Fuller tests for the log price-dividend ratio for US quarterly data 1953:2 – 1999:1. Moreover, their Horvath-Watson tests produce findings which are in contrast to Lamont's evidence. Balke and Wohar argue that the contradictory empirical findings are most likely due to the longer sample and the rapid increase in stock prices since 1995.

From the methodological point of view the low power of the tests, non-linearities and structural breaks are possible candidates for the mixed findings if we take as given the long-run validity of the present value model. From the economic point of view it is difficult to believe that stock prices are literally stuck for all times on a path simultaneously with an increasing discrepancy between stock prices and fundamentals, as the foregoing evidence in favor of the no cointegration and non-stationarity hypotheses suggest. As an alternative and more plausible hypothesis we begin by assuming that the present value model provides an empirically valid theoretical framework for the behavior US stock prices in the long-run. However, we argue that if, in the short-run, stock prices that exhibit run-ups followed by crashes which are theoretically justified either by stochastic speculative bubble models (Blanchard and Watson, 1982; West, 1987; Evans, 1991) or models of noise trading (Kirman, 1991, 1993; Shleifer, 2000), formal empirical recognition of the resulting asymmetries is necessary. In particular, the classic run-ups followed by a sudden and large reversal in stock prices suggest that stock prices exhibit some momentum away from an

[1] See, for example, Carlson and Sargent (1997), Kopcke (1997), Heaton and Lucas (2000), Balke and Wohar (2001) and Shiller (2000).

equilibrium position that is quickly corrected once the disequilibrium reaches a certain threshold.

Consequently, conventional integration and cointegration methods are not appropriate because they assume a unit root as the null hypothesis and a linear process under the alternative. As a solution we implement the momentum threshold autoregressive (MTAR) model proposed by Enders and Granger (1998) and Enders and Siklos (2001) which are equipped to provide the requisite empirical evidence for our suggestion of long-run validity of the present value approach together with short-run asymmetric stock price adjustment or error correction mechanisms. Needless to say, there are other non-linear candidate models that might explain the evolution of stock price behavior. However, the testing framework used here has the advantage that it preserves the linear long-run or cointegrating relationship preferred by the existing theoretical framework while permitting threshold adjustment in the error correction terms. In addition, the momentum framework is appealing from an economic perspective, and the relevant tests have demonstrably more power than conventional threshold adjustment models.

The paper proceeds as follows. In section 2 we provide the theoretical background necessary to justify the usage of the MTAR technique which is outlined in section 3. Section 4 presents the empirical findings on the US stock market and section 5 concludes.

2. Present Value Relations and Bubble Process Modeling

The basic framework for our analysis is a present value model which relates the real stock price, P_t, to its discounted expected future real dividends, D_t, using either a constant or a time-varying expected return (or discount rate).[2] Starting with the case of a constant expected return, $E_t R_{t+1} = R$, the present value model can be written as:

[2] Detailed descriptions of both present value models can be found in Campbell, Lo and MacKinlay (1997) and Cochrane (2001).

$$P_t = \frac{1}{(1+R)} E_t(P_{t+1} + D_{t+1}), \ \ 0 < (1+R)^{-1} < 1, \tag{1}$$

where E_t denotes the conditional expectations operator. If the transversality condition holds, then the real stock price is equal to the fundamental value $P_t = F_t$ and the market fundamentals component of the stock price in turn is equal to the present value of expected real dividends discounted at R:

$$F_t = \sum_{j=1}^{\infty} \left(\frac{1}{(1+R)} \right)^j E_t D_{t+j}. \tag{2}$$

Following Campbell and Shiller (1987) equation (2) implies:

$$P_t - R^{-1} D_t = (1+R) R^{-1} \sum_{j=1}^{\infty} \frac{1}{(1+R)^j} E_t \Delta D_{t+j}. \tag{3}$$

If stock prices and real dividends follow integrated processes of order one, $P_t, D_t \sim I(1)$, and the transversality condition holds $P_t = F_t$, then P_t and D_t are theoretically cointegrated with the cointegrating parameter R^{-1}.

The analysis of stock price behavior assuming time-varying expected returns is more complicated compared to the case of constant expected returns because the relation between prices and returns becomes non-linear. Campbell and Shiller (1988a, b) propose a log-linear approximation of the present value framework which enables to investigation stock prices behavior under any model of expected returns. Their formulation leads to the following present value equation:

$$p_t = \frac{k}{1-\rho} + E_t \left[\sum_{i=0}^{\infty} \rho^i \left((1-\rho) d_{t+1+i} - r_{t+1+i} \right) \right], \tag{4}$$

where p_t denotes the log of the stock price, d_t the log of the dividend payment and r_t the log of the time-varying discount rate. ρ and k are linearization parameters defined by $\rho = 1/(1+\exp(\overline{d-p}))$, with $(\overline{d-p})$ as the average log dividend-price ratio, and $k = -\log(\rho) - (1-\rho)\log(1/\rho - 1)$.

Rewriting equation (4) in terms of the log dividend-price ratio, and imposing the transversality condition, yields:

$$d_t - p_t = -\frac{k}{1-\rho} + E_t\left[\sum_{i=0}^{\infty} \rho^i \left(-\Delta d_{t+1+i} + r_{t+1+i}\right)\right]. \tag{5}$$

Given that changes in the log dividend and the log discount rate follow a stationary process, the log stock price and the log dividends are cointegrated with the cointegrating vector $[1,-1]$ and the log dividend-price ratio is a stationary process (see also Cochrane and Sbordone, 1988).

Relaxing the assumption of constant expected returns in favor time-varying expected returns leads to a model which does not only rely on a more realistic assumption but is also easier to investigate empirically due to the simpler structure. The empirical investigation of the log dividend-price ratio model, first, does not involve the estimation of an unknown cointegrating parameter and, second, measurement problems associated with deflating nominal stock prices and dividends by some price index do not occur. Furthermore, as shown in Timmermann (1995) when expected returns vary over time the present value model does not generally imply the existence of a stationary relationship between the integrated level variables P_t and D_t. In contrast, cointegration tests that rely on the log dividend-price ratio are, under plausible assumptions, valid in the presence of time-varying expected returns. With the exception of highly persistent expected returns (see Priestley (2001) for empirical evidence), and small samples, cointegration tests on the log dividend-price ratio tend to reject the null hypothesis of no cointegration more frequently than cointegration tests in levels. Consequently, our empirical investigation is based on the testable implications of the present value model (5) with time-varying expected returns.

The discussion of the two types of present value models relies on the assumption of the validity of the transversality condition which ensures a unique solution of the stock price, the market fundamentals stock price. If the transversality condition fails to hold, there are an infinite number of solutions. This provides the opportunity to incorporate a non-fundamental component into the present value model which allows to model deviations of stock prices from their fundamental value. While the bubble solution satisfies the Euler equation, it violates the transversality condition and the stock price is non-unique.

Speculative bubbles are mostly defined as non-fundamental stock price increases generated by extraneous events or rumors and driven by self-fulfilling expectations. After the stock price reaches a high level the bubble bursts and can then restart again (Blanchard and Watson, 1982; West, 1987; Evans, 1991).[3] Shleifer (2000) provides a model of positive feedback trader behavior in such bubbles. Shleifer's model combines arbitrageurs' trading in anticipation of noise demand with positive trading strategies. As outlined in Shleifer, this model describes the events occuring during bubble periods more accurately than do models of rational bubbles, which focus exclusively on price increases and an eventually crash. In addition, Kirman (1991, 1993) presents a theoretical explanation of how changes in market opinion among non-fundamentalist agents in financial markets may be generated and how these changes may be transmitted into asset prices. Although his model is very different to Shleifer's framework, the Kirman approach also gives rise to bubble like phenomena in which asset prices exhibit periods of tranquillity followed by bubbles and crashes.

While the above mentioned speculative bubbles and noise trader models are different theoretical approaches that explain large and persistent departures from the long-run equilibrium, all three have in common the notion that stock prices may non-fundamentally grow and collapse after reaching high levels. Furthermore, by ruling out non-negative, non-fundamental, stock price movements the models suggest an asymmetric behavior in stock prices relative to fundamentals of a particular variety to be detailed below. This pattern can be formally included in the present value model with time-varying expected returns (equation (5)) by adding on the right-hand side the term:

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[3] Unlike speculative bubbles, traditionally defined, Froot and Obstfeld (1991) propose the so-called intrinsic bubbles which depend exclusively on market fundamentals and not an extraneous events. While negative speculative bubbles are ruled out in most bubble models, Weil (1990) argues on theoretical grounds that it is possible for assets to be undervalued when the economy is in a bubble equilibrium.

$$b_t = \vartheta_t b_{t-1} u_t \,. \tag{6}$$

where b_t denotes the bubble term defined in logarithms, ϑ_t is a random variable with $E\vartheta_t = 1 + r_t$, and u_t is a stationary time series of identically, not necessarily independently distributed random variables with $E(u_t) = 1$. This quite general class of bubble processes put forward by Charemza and Deadman (1995) satisfies two conditions that are generally accepted in the literature. First, the bubble process must be a submartingale $E_{t-1}b_t = (1 + r_t)b_{t-1}$. If a bubble is present, the right-hand side of equation (5) must be augmented by the non-stationary process b_t so that d_t and p_t cannot be cointegrated with the cointegrating vector $[1,-1]$. Second, the multiplicative and lognormal formulation for $\vartheta_t = \exp(\theta_t)$ and $u_t = \exp(U_t)$ ensures the non-negativity of the bubble process (6), where $\theta_t \sim IIN(\ln(1 + r_t) - \sigma_\theta^2 / 2, \sigma_\theta^2)$ and $U_t \sim IIN(-\sigma_U^2 / 2, \sigma_U^2)$.

Another important characteristic of the bubble model (6) is its flexibility to capture bubble processes which eventually burst. Depending on the specific values of r and σ_θ^2 the bubble process can, after a period of stability, accelerate in growth, then collapse and then restart again. It is this kind of phenomenon that suggests adjustment from a disequilibrium of the momentum variety (see below). While this bubble behavior is in accordance with Evans's (1991) periodically collapsing bubbles, the bubble model (6) is less restrictive and bubble bursts are in difference to the Evans model determined by the variance of the random variable ϑ_t.

The characteristic of a non-negative bubble process and the potential to capture run-ups in stock prices before a crash suggests an asymmetry in the behavior of the log dividend-price ratio. As shown by Evans (1991) and Charemza and Deadman (1995), conventional integration and cointegration tests are misleading in the presence of such processes and tend to reject the null hypothesis of non-stationarity too often. Moreover, the findings contained in Enders and Granger (1998) and Enders and Siklos (2001) demonstrate the low power properties of conventional test approaches in the presence of asymmetric departures from the long-run equilibrium. These arguments make clear that techniques designed to capture certain types of asymmetric adjustment behavior are needed to obtain deeper insights into the characteristics of the log dividend-price ratio and stock price behavior in general. One such appropriate econometric technique is presented in the next section.

3. MTAR Model and Log Dividend-Price Ratio

Our empirical investigation relies on the momentum threshold autoregressive (MTAR) model proposed by Enders and Granger (1998) and Enders and Siklos (2001):

$$\Delta(d-p)_t = \alpha + I_t\rho_1(d-p)_{t-1} + (1-I_t)\rho_2(d-p)_{t-1}$$

$$+\sum_{i=1}^{l}\gamma_i\Delta(d-p)_t + \varepsilon_t\,, \qquad (7)$$

where the indicator variable is defined as:

$$I_t = \begin{cases} 1, \text{if} & \Delta(d-p)_{t-1} \geq \tau \\ 0, \text{if} & \Delta(d-p)_{t-1} < \tau \end{cases}. \qquad (8)$$

and τ denotes the value of the threshold. The MTAR model sets up the null hypothesis of a unit root in the log dividend-price ratio, that is, $H_0 : \rho_1 = 0$, $H_0 : \rho_2 = 0$, and $H_0 : \rho_1 = \rho_2 = 0$. If the null hypothesis is rejected, the null hypothesis of symmetric adjustment $H_0 : \rho_1 = \rho_2$ can be tested using the usual *F*-statistic. In case the null hypothesis $H_0 : \rho_1 = \rho_2$ is not rejected we can conclude in favor of a linear and symmetric adjustment in the log dividend-price ratio. Obviously, the Dickey-Fuller (1981) test is a special case of the MTAR model.

The MTAR technique is designed to detect empirically the bubble process outlined above because the theoretical potential for positive, but not negative, bubbles and the characteristic of run-ups in stock prices before a crash suggests an asymmetry in the development of the log dividend-price ratio. This bubble behavior is captured via an accumulation of changes in $(d-p)_{t-1}$ below the threshold followed by a sharp increase to the threshold, while the path of changes in $(d-p)_{t-1}$ above the threshold does not show bubble eruptions followed by a collapse.

For example, imagine the threshold in equation (8) is zero, so that $\tau = 0$. Then $\Delta(d-p)_t < 0$ is indicative of a rise in stock prices relative to dividends followed by a crash where, according to the bubble hypothesis, the departures from present value prices can be large and persistent. In contrast, a comparable accumulation of decreases in stock prices relative to dividends $\Delta(d-p)_t > 0$ and a return back to the equilibrium position is not expected. The result is asymmetric behavior in deviations from the equilibrium and an indication of the existence of bubbles that eventually burst. Accordingly, if the estimated coefficient $\hat{\rho}_2$ is statistically significant, negative, and larger in absolute value relative to the parameter $\hat{\rho}_1$, and the null hypothesis of symmetric adjustment $H_0 : \rho_1 = \rho_2$ is rejected, evidence is found in favor of the existence of bubbles in stock prices.

While the null hypotheses of the conventional Dickey-Fuller test and the MTAR models are identical, the alternative hypotheses for both differ in case of a rejection of the null hypothesis $H_0 : \rho_1 = \rho_2$. The characteristic of testing the null hypothesis of a unit root against the alternative of stationarity with MTAR adjustment permits an empirical investigation of bubbles in stock prices.

4. Empirical Results

Conventional augmented Dickey-Fuller tests, hereafter ADF, and MTAR tests are implemented for monthly US data for the 1871:1 – 2000:12 period and various subsamples (1900:1 – 2000:12, 1925:1 – 2000:12, 1871:1 – 1995:12, 1900:1 – 1995:12, 1925:1 – 1995:12) to provide a check of robustness. The selection of the years 1900 and 1925 are primilarly motivated by the dates chosen in other studies. The year 1995 is selected to take into account the extraordinary behavior of US share prices since the middle of the 1990s. For the log dividend-price ratio the Standard and Poor's stock price index and the corresponding dividend time series are taken from

Shiller's Web site http://aida.econ.yale.edu/~shiller. A description of the time series can be found in Shiller (1989, 2000). ADF and MTAR regression equations contain a constant term C or, alternatively, a constant term and a linear time trend C, T. Lag lengths l are selected according to the criteria of statistically significant coefficients at the 5 % level. The threshold τ is consistently estimated via Chan's (1993) method.

The empirical results are reported in Table 1. First, the standard ADF test is applied to the log dividend-price ratio. As can be seen in Table 1 the ADF test statistics provide mixed results for the log dividend-price ratio in samples ending in 2000. In contrast, all ADF statistics for samples ending in 1995 reject the null hypothesis of a unit root in the log dividend-price ratio. These findings are in accordance with the available evidence in the literature. It is notable for samples that include the period of extraordinary share price increases since the mid 1990s, standard integration tests often cannot reject the null hypothesis of a unit root in the log dividend-price ratio.

Table 1: MTAR Findings

	Deterministic Components	Samples		
		1871:1 – 2000:12	1900:1 – 2000:12	1925:1 – 2000:12
ADF	*C*	– 2.47	– 2.02	– 1.39
	C, T	– 3.47**	– 3.20*	– 2.49
$\hat{\tau}$	*C*	– 0.03	– 0.03	– 0.03
	C, T	– 0.03	– 0.03	– 0.03
$\hat{\rho}_1$	*C*	– 0.003 (1.07)	– 0.003 (0.69)	0.0003 (0.07)
	C, T	– 0.008 (2.09)**	– 0.009 (1.86)*	– 0.007 (1.22)
$\hat{\rho}_2$	*C*	– 0.02 (3.39)***	– 0.02 (3.06)***	– 0.03 (3.13)***
	C, T	– 0.03 (3.64)***	– 0.03 (3.49)***	– 0.03 (3.01)***
$\hat{F}_C$	*C*	6.31**	4.93*	4.90*
	C, T	8.78***	7.78**	5.25
$\hat{F}_A$	*C*	6.48***	5.75**	7.85***
	C, T	5.47**	5.26**	4.29**
l	*C*	1, 2, 5	1, 2, 5	1, 2
	C, T	1, 2, 5	1, 2, 5	1, 2

Table 1: MTAR Findings (Continued)

	Deterministic Components	Samples		
		1871:1 – 1995:12	1900:1 – 1995:12	1925:1 – 1995:12
ADF	*C*	– 3.82***	– 3.58***	– 2.63*
	C, T	– 4.55***	– 4.45***	– 3.35*
$\hat{\tau}$	*C*	– 0.03	– 0.03	– 0.03
	C, T	– 0.03	– 0.03	– 0.03
$\hat{\rho}_1$	*C*	– 0.01 (2.51)***	– 0.01 (2.32)**	– 0.007 (1.19)
	C, T	– 0.01 (3.24)***	– 0.02 (3.13)***	– 0.01 (1.99)**
$\hat{\rho}_2$	*C*	– 0.04 (3.80)***	– 0.04 (3.55)***	– 0.05 (3.84)***
	C, T	– 0.04 (3.91)***	– 0.04 (3.87)***	– 0.05 (3.50)***
$\hat{F}_C$	*C*	10.42***	9.16***	8.22***
	C, T	12.96***	12.50***	8.13**
$\hat{F}_A$	*C*	6.21***	5.46**	9.45***
	C, T	5.16**	5.14**	5.00**
l	*C*	1, 2, 5	1, 5	1, 2
	C, T	1, 2, 5	1, 5	1, 2

Table 1: MTAR Findings (Continued)

Note: *ADF* indicates *t*-statistics of the augmented Dickey-Fuller test, $\hat{\tau}$ the estimated threshold (Chan, 1993), $\hat{\rho}_1$ and $\hat{\rho}_2$ the estimated parameters of the MTAR model with *t*-statistics in parentheses, $\hat{F}_C$ and $\hat{F}_A$ the *F*-statistics for the null hypothesis of no cointegration and symmetry, respectively, and *l* the lag length. *C* and *T* are, respectively, the constant and deterministic trend terms. *, **, *** denote significant statistics at the 10 %, 5 % and 1 % level, respectively (MacKinnon, 1991; Enders and Granger, 1998; Enders and Siklos 2001).

We now turn to the results of the MTAR models. With respect to the estimated threshold it is rather remarkable that $\hat{\tau}$ is of the same value (and negative) for all samples considered. More important, with one exception only the $\hat{F}_C$ statistics are significant, and reject the null hypothesis of a unit root in the log dividend-price ratio, irrespective of the chosen deterministic components and the selected samples. This finding can be interpreted as evidence in favor of a cointegrating relationship between p_t and d_t with the cointegrating vector $[1,-1]$, i. e., the stationarity of the log dividend-price ratio. Hence, our empirical evidence supports the long-run validity of the present value model with time-varying expected returns for the US stock market.

Furthermore, while all $\hat{\rho}_2$ parameters are statistically significant at the 1 % level, the evidence for the $\hat{\rho}_1$ coefficients is mixed. More important, all point estimates for the parameter $\hat{\rho}_2$ are higher in absolute terms compared to the estimated $\hat{\rho}_1$ coefficients and the $\hat{F}_A$ statistics reject the null hypothesis of symmetric adjustment. Again the findings are insensitive with respect to the chosen deterministic specification or the sample period. According to these estimation results adjustments of accumulations of changes in the log dividend-price ratio below the equilibrium are faster compared to the short-run adjustments above the long-run equilibrium. This findings supports our hypothesis of the existence of short-run stock price increases relative to fundamentals followed by a crash. Hence, in the short-run, US share prices exhibit large and persistent deviations from the long-run equilibrium driven by speculative bubbles and/or noise trading. In the long-run, however, stock prices in the US adhere to dividends.

5. Conclusion

A large part of the current debate on US stock price behavior concentrates on the question of whether stock prices are driven by fundamentals or by non-fundamental factors. The applications of standard cointegration techniques investigating present value models provide mixed empirical evidence and the findings are partly interpretable in favor of long-run non-fundamental stock price increases. In this paper we put forward the hypothesis that a present value model with time-varying expected returns (Campbell and Shiller, 1988a, b) provides an empirically valid description of US stock price behavior in the long-run, while short-run deviations of actual share prices from present value prices are driven by non-fundamental factors like speculative bubbles (Blanchard and Watson, 1982; West, 1987; Evans, 1991) and/or noise trading behavior (Kirman 1991, 1993; Shleifer, 2000). The short-run deviations are formalized via a quite general class of processes which allow to model stock prices run-ups followed by a crash (Charemza and Deadman, 1995).

If the starting point for our empirical study is correct the log dividend-price ratio follows in the long-run a stationary process with asymmetric short-run adjustments to the equilibrium. To test this empirical implication we apply the momentum threshold autoregressive method put forward by Enders and Granger (1998) and Enders and Siklos (2001) for the US stock market covering the 1871:1 – 2000:12 period. Our empirical findings provide strong and robust support for the hypothesis that in the short-run US stock prices exhibit run-ups followed by crashes driven by speculative bubbles and/or noise trading while, in the long-run, share prices adhere to fundamentals.

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