# U.S. stock prices and moral hazard: Did the Fed contribute to the bubble in the late 1990s?

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**Abstract**

The so-called Greenspan put has received a lot of attention both among academics and the media. The Fed under Alan Greenspan is supposed to have contributed to the U.S. stock price bubble in the 1990s by having created moral hazard on the part of the investors. The hypothesis is that investors believed there was an implicit bail-out guarantee in case of a crash having observed the injection of liquidity to stabilize the stock market after the crash in 1987 and the LTCM crisis in 1998. We first identify the U.S. stock price bubble in the 1990s employing a state-space-estimation approach. Then we present empirical evidence against the Greenspan-put hypothesis using various measures of moral hazard in U.S. stock prices.

Keywords: Central bank policy, moral hazard, asset prices

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# 1 Introduction

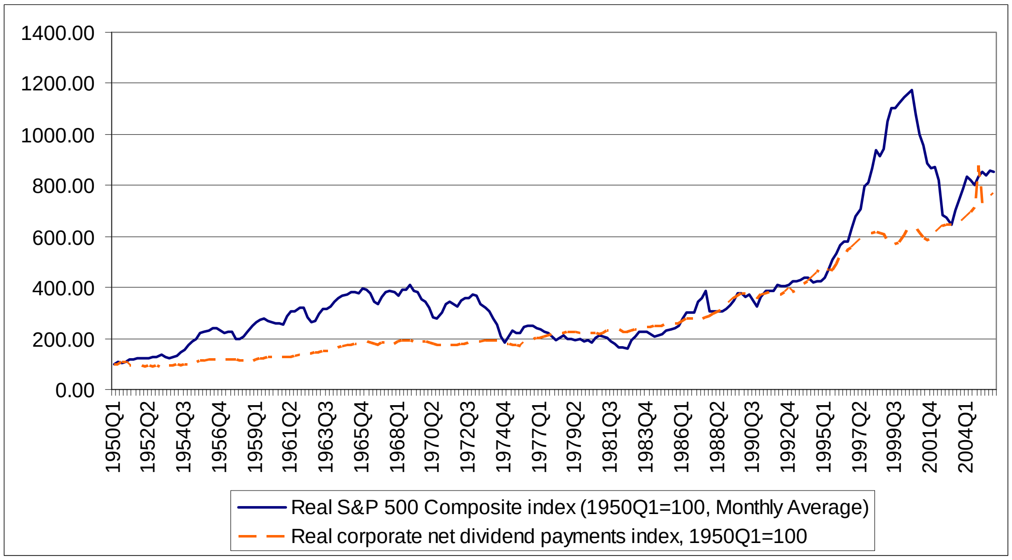


Figure 1: Real S&P 500 (solid line) and real corporate net dividend payments index (dashed line), quarterly data, 1950 Q1 to 2005 Q4

Figure (1) shows the quarterly real S & P 500 stock price index along with quarterly U.S. real corporate net dividend payments from 1950 to 2005. What stands clearly out is the huge peak in stock prices in the late 1990s. The aim of this paper is to test whether the Fed under its chairman Alan Greenspan[1] indirectly contributed to the bubble. The Fed may have done so because investors believed the Fed will bail them out in case of a stock market crash by injecting liquidity and stabilizing stock prices. Investors may have come to have this belief because the Fed has acted accordingly after the stock market crash on the Black Monday of October 1987 and after the LTCM crisis in September 1998[2]. This hypothesis, which is known as the

[1] Alan Greenspan served as chairman of the Fed from 11 August 1987 to 31 January 2006

[2] "...central banks do not respond to gradually declining asset prices. We do not respond

Greenspan-put, has been supported by leading academics and the media.

- Cecchetti et al (2000): "Many analysts have expressed concern that central banks may have created moral hazard by creating expectations that they would take remedial policy action if asset prices fall."

- Mussa (2003): "To this was added the market perception reinforced by the Fed's response to the LTCM crisis, that US monetary policy would act aggressively to countervail any sharp sell-off in equity markets – making investment in equities appear to have some characteristics of a one-way bet."

- Filardo (2004): "... investors are likely to take too much risk during the good times because investors may perceive the monetary authority as providing free downside risk insurance in the case of bad times – in the language of options, the monetary authority is offering an unpriced put."

- Mishkin and White (2003): "A fourth problem with too much focus on the stock market is that it may create a form of moral hazard. Knowing that the central bank is likely to prop up the stock market if it crashes, the markets are then more likely to bid up stock prices. This might help facilitate excessive valuation of stocks and help encourage a stock market bubble that might crash later... "

- Borio and Lowe (2003): "Moreover, reaction functions that are seen to imply asymmetric responses, lowering rates or providing ample liquidity when problems materialize but not raising rates as imbalances build up,

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to gradually rising asset prices. We do respond to sharply reduced asset prices, which will create a seizing up of liquidity in the system." Greenspan (1999)

"...Instead of trying to contain a putative bubble by drastic actions with largely unpredictable consequences, we chose, as we noted in our mid-1999 congressional testimony to focus on policies 'to mitigate the fallout when it occurs and, hopefully, ease the transition to the next expansion'". Greenspan (2004) can be rather insidious in the longer run. They promote a form of moral hazard that can sow the seeds of instability... “

- Financial Times (2001): "It’s official: there is a Greenspan put option. (...) By showing investors he [Greenspan] will rescue them come what may, he is encouraging excessive risk-taking and the formation of future bubbles.“

- The Economist (1999): "In recent years, Mr Greenspan has been taking a big risk by not having tightened policy when he first thought a bubble might be forming, or subsequently. There were plenty of signs of overheating, such as rampant consumer borrowing, that he could have used to justify higher interest rates. His second risky move was to cut rates three times last autumn in response to financial turmoil, when policy was already lax, and then to fail to take back this easing as soon as financial markets had stabilised. The Fed has thereby fostered the impression that it will slash interest rates when share prices fall sharply, but not increase rates when they shoot up. This apparent asymmetry has created a form of moral hazard that encourages investors to take bigger risks."

  and

  "Mr Greenspan’s confidence that he can use monetary policy to prevent a deep recession if share prices crash exposes an awkward asymmetry in the way central banks respond to asset prices. They are reluctant to raise interest rates to prevent a bubble, but they are quick to cut rates if financial markets tremble. Last autumn, in the wake of Russia’s default and a slide in share prices, the Fed swiftly cut rates, saying it wanted to prevent a credit crunch. As a result, share prices soared to new highs. The Fed has inadvertently created a sort of moral hazard. If investors believe that monetary policy will underpin share prices, they will take bigger risks."

- The Economist (2006): "If the Fed always cuts interest rates when asset prices tumble, but never raises them when they soar, then investors will be encouraged to take bigger risks."

Of course no one claims that moral hazard induced by monetary policy actions was solely responsible for the surge in stock prices in the late 1990s. Shiller (2001) neatly summarizes a number of factors that may have played a role in pushing up stock prices: the internet as a new technology, the spreading of the capitalist system in the world (especially China opening the economy to market oriented ideas), management and employee stock options, capital gains tax cut by a republican congress, the baby boom after WW II[3], and various psychological factors such as increased positive coverage of business by the media or the decline of inflation. Next to these factors, some authors put forward reasons such as the decline in macroeconomic volatility, which reduces the risk-premium and raises stock prices (Lettau, Ludvigson and Wachter 2006). While these explanations surely deserve attention, the moral hazard argument is especially interesting because it has a direct bearing on the more general discussion about whether monetary policy should react to asset prices. Opinions on this matter can roughly be grouped around three persons. Ben Bernanke, the current chairman of the Fed, believes that asset prices should play no role in monetary policy making over and above their impact on the inflation forecast (Bernanke and Gertler 2001). In contrast, Stephen Cecchetti argues that monetary policy can and should take asset prices into account when setting interest rates and react preemptively to a developing bubble. The reason is that once asset prices crash output might decline and as a result consumer price inflation might be affected. A sufficiently forward looking central bank might wish to avoid the extra volatility in output and inflation resulting from the asset price crash (Cecchetti et al.

[3] Birth rates in 1946-1966 were very high. These people now save for their retirement by investing in stocks. In addition demand for goods is generally high with a larger population which results in higher profits of firms and thus a high price-earnings ratio (Shiller 2001).

2000). Finally, Alan Greenspan holds the view that it is impossible to identify asset price misalignments in the first place. Consequently, a central bank cannot react to asset price movements. All it can do is to stand ready and limit the damage after a stock market crash by providing liquidity to the market (Greenspan 1999; Greenspan 2004)[4]. Not only disagree Cecchetti et al. (2000) with the view that asset price bubbles are impossible to identify[5], but Greenspan's position might have lead to the alleged moral hazard behaviour on the part of investors. If that was true monetary policy-makers might rather opt for acting preemptively against rapidly rising asset prices to avoid both the moral hazard problem and any adverse effects on output and inflation should the bubble burst.

The remainder of the paper is structured as follows. In the next section we outline our empirical strategy, section 3 gives a description of the data, section 4 gives a literature overview, section 5 presents unit root tests and cointegration analysis, section 6 reports results from a state-space estimation to identify asset price misalignments for the years 1950 to 2005. The seventh section then uses theoretical models to arrive at measures of moral hazard in monetary policy and presents empirical evidence against the existence of the so-called Greenspan put in U.S. stock prices. Section 8 concludes.

## 2 Empirical strategy

To be able to analyse factors that might have had an impact on stock price bubbles, the bubble must be identified first. In the literature the term bubble is mostly used for any kind of variation in asset prices that can't be explained by fundamentals. Therefore we start from a standard present value model. The stock price is the discounted sum of expected future dividend payments.

[4]See footnote 2.

[5]Cecchetti et al. (2000) argue that a central bank uses the output gap to gauge inflation, which requires a judgement about unobserved output. Analogously it shouldn't be impossible to arrive at a judgement about the fundamental value of asset prices.

Instead of imposing the transversality condition we explicitly allow for a bubble term in the stock price equation. This formulation allows to use unit root and cointegration tests as a preliminary check for bubbles. After having established that bubbles can't be ruled out by these tests we cast the problem in terms of a state-space model and use the Kalman filter technique to get an explicit estimate of the unobserved bubble term.

In the second stage of our analysis the identified bubble term is used to test whether investor moral hazard induced by the Fed's past actions had any impact on it. To do so we rely on two theoretical models that address the problem of moral hazard in U.S. monetary policy. We construct various measures of moral hazard on the basis of these models and test whether they had an impact on the bubble term itself or whether they are significant in the stock price equation.

Our results are that unit root and cointegration tests indicate the presence of a bubble and we are indeed able to identify a statistically significant bubble component in U.S. stock prices in the late 1990s using the state-space approach. Regarding the measures of moral hazard none of them turns out to have a significant impact on either the bubble term itself or on stock prices directly.

There are three basic criticisms to our approach. First, as Cogley (1999) argues, researchers trying to detect a bubble, e.g. at central banks, have difficulties in observationally distinguishing a bubble from an omitted unobserved fundamental. This is an important criticism which in principal applies to our approach. However, the crucial difference is that we take the identification of the bubble one step further and use it to test one specific hypothesis, the Greenspan put hypothesis. That is, we treat the unobserved moral hazard behaviour on the part of investors as the omitted variable and test whether it had any impact on the identified bubble. In addition to that, Cecchetti et al's (2000) argument applies. Estimating the output gap requires a judgement about the level of potential output, which is common practice at central banks. Equally, identifying a bubble requires a judgement about the fundamentals, which has its problems but which is not impossible. Second, our test for a bubble is principally also a test of the adequacy of the present value model. However, this criticism applies only if one uses the present value to reject the presence of the bubble. Then, one wouldn't know whether the rejection is due to there truly being no bubble or due to the model being inadequate. In contrast, not rejecting a bubble poses no problem in this regard. However, third, rejecting the moral hazard hypothesis might mean the measures of moral hazard are right but have truly no statistically significant impact. Or the measures of moral hazard are false. Since moral hazard behaviour is not observable we must rely on indirect measures. The next best option is then to use theory to arrive at those measures, which is our approach. At the very least, our results indicate that the predictions of the theoretical models of Miller, Weller and Zhang (2002) and Illing (2001) are not confirmed by the data.

# 3 Data

The stock price index is the S&P 500 composite index from 1950 Q1 to 2005 Q4. The dividend series are seasonally adjusted U.S. net corporate dividend payments from 1950 Q1 to 2005 Q4. Both series are deflated by the seasonally adjusted U.S. consumer price index. The real interest rate is the annualized three-month U.S. treasury bill rate minus the CPI based inflation rate.

Data for the various measures of moral hazard are constructed from different sources. The stock market crash probability is Shiller's Crash Confidence Index from a survey among institutional investors available on his website[6]. It is the percentage of respondents who think that the probability of a stock market crash in the next six months is less than 10%. The data are collected

[6]For more information on Shiller's investor confidence indices: http://icf.som.yale.edu/confidence.index/

semi-annually from October 1989 to April 2001 and monthly afterwards. To arrive at quarterly data to make frequencies match, we have linearly interpolated Shiller's survey data from October 1989 to April 2001 and averaged from July 2001 onwards. Miller et al's (2002) measure of moral hazard has been constructed by taking the ratio of the level of current dividends to their level at the stock price peak in 1987 Q3 before the crash, to their level at 79% of the stock price peak in 1998 Q2 and to a simple average of the two values. Real credit growth is the real growth of total debt outstanding of the U.S. domestic nonfinancial sectors deflated by the CPI. The debt gap measure has been constructed by applying the HP-filter to the ratio of total debt outstanding to seasonally adjusted GDP with a smoothing parameter of 1600.

# 4 Literature overview

There are various approaches in the literature to testing for asset price bubbles[7]. The starting point is mostly the present value model of stock prices. The earliest tests by Shiller (1981) and LeRoy and Porter (1981) were variance bounds test. Their intuition is that the ex-ante expected stock price should be less volatile than the ex-post realized value because it contains the forecast error of dividends. This implies a restriction on the variances of the observed prices at time $t$ and their ex-post realized values which can be tested. Their finding is that the variance restriction is violated and the existence of bubbles can't be ruled out. Of course, all tests for bubbles based on the present value model are at the same time tests of the present value model itself. West (1987) proposed a way to overcome this difficulty. The idea is to obtain the parameters of the present value model by estimating an Euler equation and an autoregressive process for dividends. Misspecifica-

[7] Gurkaynak (2005) provides a thorough overview of empirical tests for asset price bubbles.

tion tests are applied to ensure the validity of the estimates. They can then be used to re-construct the relation between the stock price and fundamentals. In a second step stock prices can be estimated using the present value model. If the two estimated relationships differ it is possible to distinguish model misspecification and the presence of a bubble. West can't rule out the presence of a bubble either. Another strand of the literature exploits unit root and cointegration characteristics of the present value model taking into account possible unobversables. Notably Diba and Grossman (1987, 1988a, 1988b) follow this approach and see whether they can rule out an explosive rational bubble in stock prices[8]. After applying various unit root and cointegration tests they conclude that stock prices don't have an explosive rational bubble component. Psaradakis, Sola and Spagnolo (2001) examine wholesale prices and the money supply during the German hyperinflation. They apply a specific unit root test and find an explosive root in their data. This approach has been criticised by Evans (1991) who presents an example of a periodically collapsing bubble which never bursts. By subjecting a simulated periodically collapsing bubble to Diba and Grossman's (1988) test he shows that unit roots tests fail to detect this kind of bubble[9]. The literature on marko-switching processes in stock prices and dividends tries to overcome this problem. Hall, Psaradakis and Sola (1999) use a markov-switching model to identify periods when asset prices are in an explosive regime while fundamentals are not. They apply it to consumer prices, the money supply and the exchange rate and identify periods of rational explosive bubbles in consumer prices and the exchange rate. Psaradakis, Sola and Spagnolo (2004) use a Markov error-correction model to identify periods of collapsing bubbles

[8] This approach will be discussed in detail and applied below.

[9] Taylor and Peel (1998) use a unit root test that is robust to periodically collapsing components in stock prices and reject the hypothesis of a stock price bubble in the U.S. Sarno and Taylor (1999) apply the same test to East Asian stock price indices and confirm the existence of bubbles there.

and conclude against their existence[10]. Instead of concentrating on modelling periodic collapses of bubbles, Wu (1995, 1997) focuses on the fact that the bubble is unobserved by the econometrician and proposes a Kalman filter approach to testing for bubbles. The Kalman filter allows for the estimation of an unobserved variable within a state-space model, e.g. the bubble term in the present value model. Applying this technique to U.S. exchange rate data he finds no support for the existence of bubbles. However, testing for a bubble in U.S. stock prices he can identify stock price bubbles.

In contrast there is hardly any literature on moral hazard and monetary policy. Only two papers address the problem of theoretically modelling moral hazard in monetary policy. Illing (2001) shows why it may be rational for a central bank to react asymmetrically to asset price movements building on a framework by Allan and Gale (2000). Because it is costly to let highly leveraged firms go bankrupt on a large scale the central bank has an incentive to inject liquidity in case of an aggregated shock. This incentive is higher, the higher the leverage in the economy. Rational investors will anticipate the resulting capital gain from the reduced real debt burden and include it in their stock valuation. Miller, Weller and Zhang (2002) can explain the observed low risk-premium in the late 1990s by incorporating the value of an implicit insurance of investors against downside risk. Related but not modelling stock price misalignments is the paper by Borio and Lowe (2002). They study ex-ante indicators of financial crises and show that the deviation of the ratio of credit to GDP from trend is a fairly good indicator of financial crises.

Finally, to the best of our knowledge, there is no paper which tries to evaluate empirically the hypothesis of moral hazard in monetary policy.

In the following we set up the present value model of stock prices and apply unit root and cointegration tests on U.S. stock price data. After being

[10] Furthermore, Froot and Obstfeld (1991) propose a model where the stock price bubble is a function of dividends, which is called an intrinsic bubble. Their own test and a test by Driffil and Sola (1998) yields ambiguous results regarding the presence of intrinsic bubbles.

able to reject the null hypothesis of no bubble we proceed to estimating a state-space model using the Kalman filter which allows to obtain an actual series with confidence bands for the bubble term and use measures of moral hazard to test the moral hazard hypothesis.

# 5 The present value model and testable implications for bubbles

As a preliminary test of bubbles in U.S. stock prices we follow Diba and Grossman (1988) who use the standard present value model to derive testable implications for bubbles. They explicitly allow for an unobserved variable that might influence the stock price over and above divididends and a possible bubble. In their analysis they use data up to 1986 and can rule out rational explosive bubbles. In contrast, extending the data range up to 2005 we can't rule out the existence of either an unobserved variable influencing stock prices or the presence of a bubble. Consider the stock price according to the present value model

$$P_t = (1+R)^{-1} E_t \left( P_{t+1} + D_t + u_t \right) \tag{1}$$

where $P_t$ is the stock price at the beginning of period $t$, $D_t$ is the dividend paid during period $t$, $R$ is the constant real interest rate[11] and $u_t$ is a variable that is unobserved by the researcher but taken into account by market participants. The fundamental stock price $F_t$ is the discounted sum of expected future dividends $D_t$ plus the unobserved variable $u_t$.

$$F_t = \sum_{i=0}^{\infty} (1+R)^{-i} E_t (D_{t+i} + u_{t+i}) \tag{2}$$

[11] Assuming a constant real interest rate is standard in the literature. As a check we ran all tests allowing for a time-varying real interest rate and the results didn't change qualitatively (see appendix).

The general solution to the stock price equation is

$$P_t = \sum_{i=0}^{\infty} (1+R)^{-i} E_t(D_{t+i} + u_{t+i}) + B_t \tag{3}$$

where $B_t$ is the bubble term and obeys

$$E_t B_{t+1} = (1+R)\, B_t \tag{4}$$

Note that since $1 + R > 1$ the present value model predicts explosive bubbles, i.e. the bubble should grow at the rate of real interest. Given this setup Diba and Grossman (1988) derive testable implications for the presence of a bubble in stock prices. If there are no bubbles and if, in addition, the first differences of the unobservable and the first differences of dividends are stationary, then the first differnces of stock prices should be stationary too. Moreover, if there are no bubbles and the unobservable is stationary in levels and dividends are stationary in first differences then stock prices and dividends should be cointegrated of order (1,1). More formally,

$$\text{If } B_t = 0\ \forall t \text{ and } \Delta u_t \sim I(0) \text{ and } \Delta D_t \sim I(0),\ \text{ then } \Delta P_t \sim I(0) \tag{5}$$

$$\text{If } B_t = 0\ \forall t \text{ and } u_t \sim I(0) \text{ and } \Delta D_t \sim I(0),\ \text{ then } \begin{pmatrix} P_t \\ D_t \end{pmatrix} \sim CI(1,1) \tag{6}$$

Confirming these results would be evidence against the existence of rational bubbles. Rejecting them, however, doesn't necessarily point to the existence of bubbles since, in the first case, it could be that the first differences of the unobservable are non-stationary, while in the second case, the level of the unobservable could be non-stationary.

## 5.1 Unit root and cointegration tests

In the following we report results of unit root tests on stock prices and dividends, as well as results of cointegration tests on stock prices and dividends[12]. Augmented Dickey-Fuller tests have been carried out on the real stock price in levels and differences and the same for real dividends. We included a trend in the levels regression on the stock price and dividends but excluded it in the regression of first differences as well as in the cointegrating regression. An intercept was always included. The lag length was chosen on the basis of the Akaike criterion, the Schwarz Bayesian Criterion and the LR-ratio. In most cases the three criteria agreed on the optimal lag length. Where they didn't agree all suggested lag lengths have been tried. The results were qualitatively the same. The fifth line in table 1 contains the values of the t-statistics on the coefficient $\rho$ in the ADF regression with the corresponding 5% critical values in line six.

| | ADF regression $\Delta y_t = \mu + \gamma t + \rho y_{t-1} + \sum_{i=1}^{n} \beta_i \Delta y_{t-i} + \epsilon_t$ $H_o : \rho = 0$, unit root in $y_t$ $T = 224$ | | | | |
|---|---|---|---|---|---|
| $y_t$ | $P_t$ | $\Delta P_t$ | $D_t$ | $\Delta D_t$ | $\binom{P_t}{D_t}$ |
| | | $\gamma = 0$ | | $\gamma = 0$ | $\gamma = 0$ |
| n$^o$ of lags | 4 | 3 | 2 | 1 | 3 |
| t-statistic on $\rho$ | $-1.107$ | $-10.864^*$ | $-1.363$ | $-26.900^*$ | $-2.600$ |
| 5% critical value | $-3.423$ | $-2.876$ | $-3.423$ | $-2.876$ | $-3.380$ |

Table 1: ADF unit root and cointegration tests on the real stock price and dividends

The results show that both the price series and the dividend series are $I(1)$ in levels and $I(0)$ in first differences. Column six indicates that the stock prices and dividends are not cointegrated at the 5% level. The predictions

[12] The tests are applied to the levels of all variables. For a logarithmic version including a time-varying real interest rate see the appendix.

of the present value model in (5) is clearly confirmed, while (6) is rejected. The main result to take away is that the test clearly rejects the prediction that a bubble should be explosive. Moreover, the results indicate that the unobservable $u_t$ is not $I(0)$ in levels but more likely to be $I(1)$. This means that there is quite likely an unobserved variable rather than an explosive bubble component that influences stock prices.

To further investigate the possibility of an explosive bubble component in stock prices we employ another test which has been proposed by Bhargava (1986). Next to a test statistic for the null hypothesis of a unit root versus stationarity he provides a direct test of the null of a unit root against an explosive alternative[13]. The test for the null of a simple random walk against the stationary alternative is based on the statistic

$$R_1 = \frac{\sum_{t=2}^{T} (y_t - y_{t-1})^2}{\sum_{t=1}^{T} (y_t - \bar{y})^2} \tag{7}$$

One rejects the null of a random walk in favour of stationarity in $y_t$ if $R_1$ becomes larger than some critical value. This is intuitive because the denominator of $R_1$ grows much faster for a non-stationary series than for a stationary one. The test for the null of a simple random walk against the explosive alternative is based on the statistic

$$N_1 = \frac{\sum_{t=2}^{T} (y_t - y_{t-1})^2}{\sum_{t=2}^{T} (y_t - y_1)^2} \tag{8}$$

One rejects the null of a random walk in favour of the explosive alternative in $y_t$ if $N_1$ becomes smaller than some critical value. Intuitively, this is because for an explosive series the denominator of $N_1$ grows much faster

[13] For convenience, Bhargava's (1986) test statistics are reproduced in the appendix.

than for a simple random walk. $R_2$ and $N_2$ work the same way for the null of a random walk with drift.

| | Bhargava test for stationarity<br>$H_o : y_t$ is random walk<br>$H_1 : y_t$ is stationary<br>$T = 224$ | | |
|---|---|---|---|
| $y_t$ | $P_t$ ($\Delta P_t$) | $D_t$ ($\Delta D_t$) | Residuals from cointegrating regression |
| Bhargava test statistic | $R_2 = 0.0217$<br>($R_2 = 1.1654^*$) | $R_2 = 0.0424$<br>($R_2 = 2.5209^*$) | $R_1 = 0.0703$<br>($R_1 = 1.7759^*$) |
| 5% critical value | 0.1597 | 0.1597 | 0.1194 |

Table 2: Bhargava tests for stationarity on the real stock price, dividends and cointegration residuals. Values for first differences in parentheses. Asteriks denote rejection of the null. Test statistic must exceed critical value.

Bhargava (1986) tabulates critical values, however only up to a sample size of 100. Since our sample size in this case is 224 we calculated the corresponding 5% critical value by Monte Carlo simulations[14]. In table 2 the null hypothesis is that a variable follows a random walk against the stationary alternative. The null is rejected for test statistics exceeding their critical value. In our case we can't reject the null of a random walk for the stock price, dividends and the residuals from the cointegrating regression. This supports the view that the failure of stock prices and dividends to cointegrate is due to some unobserved $I(1)$ variable rather than an explosive rational bubble.

Table 3 presents results for tests of the null of a random walk against the explosive alternative. The null is rejected for test statistics below the critical value. In this case the null of a random walk can't be rejected for the stock

[14] The simulations were cross-checked by first replicating those critical values tabulated by Bhargava (1986). Simulations were carried out running 100000 replications.

| | Bhargava test for explosive roots<br>$H_o : y_t$ is random walk<br>$H_1 : y_t$ is explosive<br>$T = 224$ | | |
|---|---|---|---|
| $y_t$ | $P_t$ ($\Delta P_t$) | $D_t$ ($\Delta D_t$) | Residuals from cointegrating regression |
| Bhargava test statistic | $N_2 = 0.0168$ | $N_2 = 0.0096^*$ | $N_1 = 0.0624$ |
| 5% critical value | 0.0097 | 0.0097 | 0.0027 |

Table 3: Bhargava tests for explosive roots on the real stock price, dividends and cointegration residuals. Values for first differences in parentheses. Asteriks denote rejection of the null. Test statistics must be lower than critical value.

price and the residual. Puzzling is that dividends seem to appear explosive, although only marginally.

Overall, the tests confirm the absence of rational explosive bubbles in stock prices, while at the same time indicating the presence of some unobserved variable that follows a random walk. However, what the test doesn't provide information about is at what times the unobserved variable had an impact on stock prices and whether this influence was economically and statistically significant. Moreover, there is another important caveat about using unit root and cointegration tests to identify rational explosive bubbles that was put forward by Evans (1991). He has shown the theoretical possibility of periodically collapsing bubbles. Rational bubbles would then only appear explosive during their expansion, while the subsequent collapse could make the bubble look like an $I(1)$ variable or stationary. This would mean that tests based on random walk and cointegrating properties wouldn't detect a bubble since they focus on the explosive characteristic.

Summing up, the unit root/cointegration approach has two shortcomings. First, while it confirmed the presence of some unobserved variable in U.S. stock prices, rational bubbles can be periodically collapsing and might therefore appear to be integrated of order one instead of explosive as theory suggests (Evans 1991). Thus, periodically collapsing bubbles cannot be ruled out. Second, it doesn't provide any information about the level or significance of the bubble at different points in time. As Evans (1991) argues it is conceivable that a bubble doesn't exist at all points in time. We are especially interested whether there was a bubble in the late 1990s. Thus to further investigate the presence of bubbles we cast the present value model in a state-space representation and employ the Kalman filtering technique to get an actual estimate of the size and significance of the bubble.

# 6 Estimation of a state-space model

In the previous section it has been shown that pure unit root and cointegration tests are unable to identify periodically collapsing bubbles. The state-space model is better suited to find a possible bubble. It uses the Kalman filtering technique to arrive at an actual time-series estimate of a possible bubble, i.e. it can provide information about the size and significance of a possible bubble. This estimate can then be used to test for determinants. Further advantages of the state-space approach are that it is readily applied to the present value model, it is intuitive and computationally feasible.

## 6.1 The present value model in state-space representation

Next, we formulate the present value model in its logarithmic version to fit it into a state-space representation. Consider again the stock price

$$P_t = \frac{E_t\left(P_{t+1} + D_t\right)}{1 + R_t} \tag{9}$$

where $P_t$ is the beginning of period stock price, $D_t$ is the dividend paid during period $t$, $R_t$ is the return on the stock from period $t$ to $t+1$ and $E_t$ is the expectation at time $t$. Note that we don't explicitly include an unobserved variable, leaving its impact to enter the bubble term. Rearranging and taking logarithms yields

$$r_t = E_t p_{t+1} - p_t + \ln(1 + e^{E_t(d_t - p_{t+1})}) \tag{10}$$

where lower case letters denote logarithms of upper case letters and $r_t = \ln(1 + R_t)$.Taking a first-order Taylor expansion around $x_t = E_t(d_t - p_{t+1})$ yields

$$r_t = k + (1 - \psi)E_t d_t + \psi E_t p_{t+1} - p_t \tag{11}$$

where $\psi = \frac{1}{1+e^{\overline{d-p}}}$ and $k = -\ln\psi + (1-\psi)\ln(\frac{1}{\psi} - 1)$. Rearranging and iterating forward results in

$$p_t = \frac{k}{1-\psi} + (1-\psi)\, E_t \sum_{i=0}^{\infty} \psi^i d_{t+i} - E_t \sum_{i=0}^{\infty} \psi^i r_{t+i} + b_t \tag{12}$$

with

$$E_t(b_{t+i}) = \left(\frac{1}{\psi}\right)^i b_t \tag{13}$$

First difference this equation to get

$$\Delta p_t = (1-\psi) \sum_{i=0}^{\infty} \psi^i \left[E_t d_{t+i} - E_{t-1} d_{t+i-1}\right] - \sum_{i=0}^{\infty} \psi^i \left[E_t r_{t+i} - E_{t-1} r_{t+i-1}\right] + \Delta b_t \tag{14}$$

In case of a constant real interest rate $r$ (12) reduces to

$$p_t = \frac{k-r}{1-\psi} + (1-\psi)\, E_t \sum_{i=0}^{\infty} \psi^i d_{t+i} + b_t \tag{15}$$

and (14) to

$$\Delta p_t = (1-\psi) \sum_{i=0}^{\infty} \psi^i \left[E_t d_{t+i} - E_{t-1} d_{t+i-1}\right] + \Delta b_t \tag{16}$$

In following we sketch the principles of the state-space approach and its estimation[15]. We then apply it to the present value model. The state-space model consists of the system of equations:

$$\underset{(n\times 1)}{y_t} = \underset{(n\times k)(k\times 1)}{Ax_t} + \underset{(n\times r)(r\times 1)}{Hs_t} + \underset{(n\times 1)}{w_t} \tag{17}$$

$$\underset{(r\times 1)}{s_{t+1}} = \underset{(r\times r)(r\times 1)}{Fs_t} + \underset{(r\times 1)}{v_{t+1}} \tag{18}$$

(17) is the measurement or observation equation, which describes the relation between observed and unobserved variables, where $y_t$, and $x_t$ are vectors of observed variables and $s_t$ is a vector of unobserved variables and $w_t$ is an error term. (18) is the state equation, which describes the dynamics of the unobserved variables vector $s_t$, where $v_{t+1}$ is an error term. $A$, $H$ and $F$ are coefficient matrices that have to be estimated from the data. Maintained assumptions are

$$E\left(v_t v_\tau'\right) = \begin{cases} Q \text{ for } t = \tau \\ 0 \text{ otherwise} \end{cases} \tag{19}$$

$$E\left(w_t w_\tau'\right) = \begin{cases} R \text{ for } t = \tau \\ 0 \text{ otherwise} \end{cases} \tag{20}$$

$$E\left(v_t w_\tau'\right) = 0 \text{ for all } t \text{ and } \tau \tag{21}$$

$$E\left(v_t s_1'\right) = 0 \text{ for all } t \tag{22}$$

$$E\left(w_t s_1'\right) = 0 \text{ for all } t \tag{23}$$

The objective of the Kalman filter is to find linear least squares forecasts

[15] For a thorough discussion refer to Hamilton's (1994) textbook.

of the state vector $s_t$. Suppose the coefficient matrices were known, then

$$\begin{aligned} \hat{s}_{t+1|t} &= \hat{E}\left(s_{t+1} \mid y_t, y_{t-1}, ..., y_1, x_t, x_{t-1}, ..., x_1\right) \\ &= F\hat{E}\left(s_t \mid y_t, y_{t-1}, ..., y_1, x_t, x_{t-1}, ..., x_1\right) \\ &= F\hat{s}_{t|t} \end{aligned} \tag{24}$$

$\hat{s}_{t|t}$ is the forecast $\hat{s}_{t|t-1}$ updated by new information in $y_t$.

$$\begin{aligned} \hat{s}_{t|t} &= \hat{s}_{t|t-1} + \left\{E\left[\left(s_t - \hat{s}_{t|t-1}\right)\left(y_t - \hat{y}_{t|t-1}\right)'\right]\right\} \\ &\quad \times \left\{E\left[\left(y_t - \hat{y}_{t|t-1}\right)\left(y_t - \hat{y}_{t|t-1}\right)'\right]\right\}^{-1} \times \left(y_t - \hat{y}_{t|t-1}\right) \end{aligned} \tag{25}$$

Updating the forecast is done by adding to it the unanticipated part of the new piece of information $y_t - \hat{y}_{t|t-1}$ weighted by a matrix, which could be interpreted as the correlation of the state and measurement equation forecast error. The larger the correlation the more weighs the arrival of new information. To compute the updated forecast one needs a forecast of $y_t$.

$$\begin{aligned} \hat{y}_{t|t-1} &= \hat{E}\left(y_t \mid y_{t-1}, y_{t-2}, ..., y_1, x_t, x_{t-1}, ..., x_1\right) \\ &= Ax_t + H\hat{s}_{t|t-1} \end{aligned} \tag{26}$$

The Kalman filter is started by setting starting values for $s_{1|0}$ and an associated mean squared error

$$P_{1|0} = E\left\{\left[s_1 - E\left(s_1\right)\right]\left[s_1 - E\left(s_1\right)\right]'\right\} \tag{27}$$

For stationary processes $s_{1|0}$ is set to the unconditial mean of the process and the initial mean squared error can be computed from the matrices $F$ and $Q$. For non-stationary processes $s_{1|0}$ is set to some best guess and $P_{1|0}$ arbitrarily high to reflect the uncertainty about $s_{1|0}$. Iterate over (24) to (26) to find the series $\left\{\hat{s}_{t|t-1}\right\}_{t=1}^{T}$ and $\left\{P_{t|t-1}\right\}_{t=1}^{T}$.

The system (17) and (18) is estimated by maximising the loglikelihood function

$$\sum_{t=1}^{T} \log f\left(y_t \mid y_{t-1}, ..., y_1, x_t, x_{t-1}, ..., x_1\right) \tag{28}$$

To do so, set the matrices $A$, $H$, $F$, $Q$, $R$ to some initial values, find the series $\left\{\hat{s}_{t|t-1}\right\}_{t=1}^{T}$ and $\left\{P_{t|t-1}\right\}_{t=1}^{T}$ by the Kalman filter and calculate the value of the loglikelihood function. Numerical optimisation procedures can be employed to maximise the loglikelihood function.

We follow Wu (1997) and estimate a state-space system with the stock price equation (16) as measurement equation and the unobserved bubble process (13) as state equation. The difference to Wu (1997) at this point is that while he uses data up to 1992 we extend the sample range up to 2005. Also we estimate a version of the model with a time-varying interest rate, while Wu (1997) assumes a constant real interest rate throughout. The stock price equation is first-differenced because the stock price and dividends series are non-stationary. Indeed, log dividends are found to follow an ARIMA $(h, 1, 0)$ process[16]

$$\Delta d_t = \mu + \sum_{i=1}^{h} \varphi_i \Delta d_{t-i} + \delta_t \tag{29}$$

where the lag length $h$ is determined by the data. (29) can be written in the companion form

$$z_t = u + B z_{t-1} + \nu_t \tag{30}$$

where $z_t = (\Delta d_t, \Delta d_{t-1}, ..., \Delta d_{t-h+1})'$, $u = (\mu, 0, ..., 0)'$ and $\nu_t = (\delta_t, 0, ..., 0)'$ are $h$-vectors and

$$B = \begin{pmatrix} \varphi_1 & \varphi_2 & \cdots & \varphi_{h-1} & \varphi_h \\ 1 & 0 & ... & 0 & 0 \\ 0 & 1 & ... & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & 0 & ... & 1 & 0 \end{pmatrix} \tag{31}$$

[16] For all variables the time-series processes have been estimated.

is a $h \times h$-matrix. According to Wu (1997) and Campbell and Shiller (1987) the solution to (16) can then be obtained using (30) in

$$\Delta p_t = \Delta d_t + M \Delta z_t + \Delta b_t \tag{32}$$

where $M = gB(I-B)^{-1}\left[I-(1-\psi)(I-\psi B)^{-1}\right]$ and $g = (1,0,...,0)$ are $h$-row vectors and $I$ the $h \times h$-identity matrix.

## 6.2 Empirical results

In our case to determine the optimal lag length $h$ of the first differences of dividends we used the AIC and SBC criteria as well as an LR-ratio test. The resulting optimal lag length is $h = 5$ as reported in table 8. Together with (13) this implies the following state-space model

$$\Delta p_t = \sum_{i=0}^{5} \alpha_i \Delta d_{t-i} + \Delta b_t \tag{33}$$

$$b_t = \gamma b_{t-1} + \eta_t \tag{34}$$

Table 4 reports the estimation results of the parameters $\alpha_i$ and $\eta_t$ together with their standard errors and significance levels. Initial values for the coefficients were taken from a simple OLS regression of the measurement equation.

Clearly all coefficients except those on the lags of the first differences of log dividends are significant at the 5% level. Note that the coefficient on the bubble term is significant and near and slightly larger than one. However, a Wald coefficient test on the restriction $H_o : \gamma = 1$ can't reject the null. Also the estimated standard deviation of the state equation is significant. Our finding appears to be in line with the notion of periodically collapsing bubbles which would make the bubble term appear integrated of order one or zero rather than explosive. Figure (2) shows the estimated bubble with

| | coefficient | std. error | prob. |
|---|---|---|---|
| $\Delta d_t$ | 0.4124 | 0.1342 | 0.0021 |
| $\Delta d_{t-1}$ | 0.1937 | 0.1536 | 0.2074 |
| $\Delta d_{t-2}$ | $-0.1754$ | 0.1847 | 0.3421 |
| $\Delta d_{t-3}$ | $-0.0962$ | 0.2138 | 0.6527 |
| $\Delta d_{t-4}$ | $-0.0648$ | 0.1641 | 0.6930 |
| $\Delta d_{t-5}$ | 0.2070 | 0.1782 | 0.2453 |
| $b_{t-1}$ | 1.0011 | 0.0072 | 0.0000 |
| $\sigma_{\eta_t}$ | 0.0585 | 0.0023 | 0.0000 |

Table 4: Estimation results of coefficients in stock price and bubble equation

the corresponding 5% confidence bands[17].

There are clearly periods in which the estimated bubble term is positive and significant, e.g. during most of the late 1950s through the early 1970s and especially in the late 1990s. Also note that the model identifies the level of the S&P 500 in October 1987 as a bubble. Getting a precise estimate for the size of the bubble requires an assumption about the size of the bubble at the starting date. Conservatively we have set this starting value to zero in the estimation[18]. Even with this assumption the bubble is significant during plausible periods. However, even without the exact size of the bubble we can test determinants that might have influenced the bubble.

Obviously the assumption of a constant real interest rate might be quite restrictive and responsible for the high stock price index. Therefore we next estimate the same model as above including a time-varying interest rate. In particular, we use the following specification.

[17] We report results based on smoothed estimates of the state equation, which means that in (24) the Kalman filter uses all available observations $t = 1, ..., T$ to estimate the unobserved state

$$\hat{s}_{t+1|T} = \hat{E}\left(s_{t+1} \mid y_T, y_{T-1}, ..., y_t, ..., y_1, x_T, x_{T-1}, ..., x_t, ..., x_1\right) \tag{35}$$

[18] Theoretically, a rational bubble can only start at the first day of trading (Diba and Grossman 1988b). Thus, we also ran the estimation setting the starting value of the state value to a very small number with the same results.

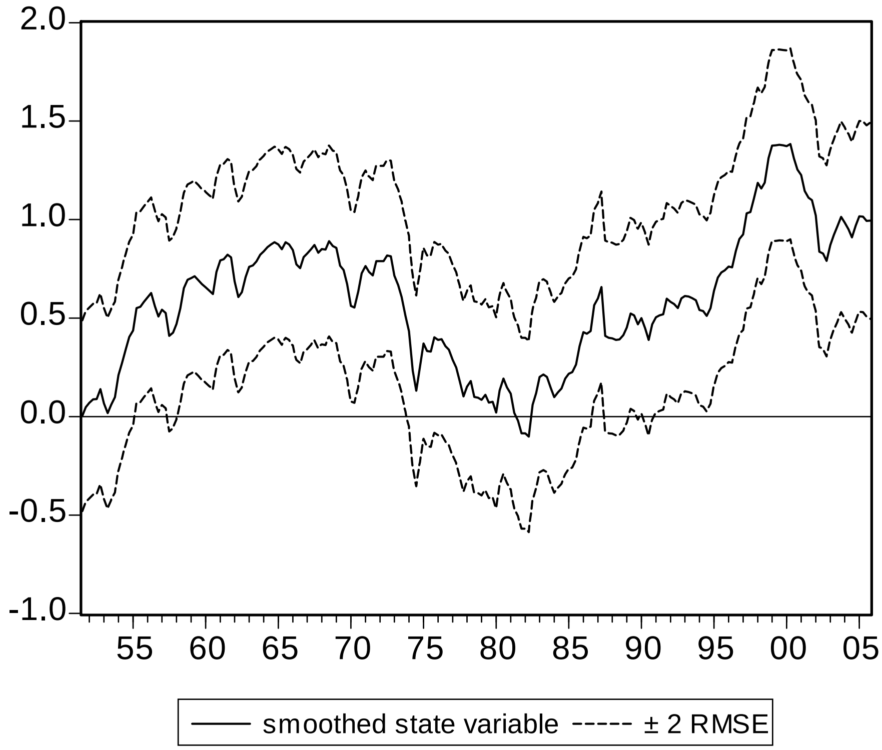


Figure 2: Smoothed estimate of state variable with 5% confidence bands

$$\Delta p_t = \sum_{i=0}^{5} \alpha_i \Delta d_{t-i} + \sum_{j=0}^{7} \beta_j \Delta r_{t-j} + \Delta b_t \quad (36)$$

$$b_t = \gamma b_{t-1} + \eta_t \quad (37)$$

The lag length of the real interest rate series is taken from table 8 as before and is also based on the AIC, SBC and LR-ratio. Table 5 reports the results.

Again the coefficients on the lags of the first differences of dividends and the real interest rate are insignificant while those on contemporaneous differ-

| | coefficient | std. error | prob. |
|---|---|---|---|
| $\Delta d_t$ | 0.4124 | 0.1342 | 0.0021 |
| $\Delta d_{t-1}$ | 0.1937 | 0.1536 | 0.2074 |
| $\Delta d_{t-2}$ | $-0.1754$ | 0.1847 | 0.3421 |
| $\Delta d_{t-3}$ | $-0.0962$ | 0.2138 | 0.6527 |
| $\Delta d_{t-4}$ | $-0.0648$ | 0.1641 | 0.6930 |
| $\Delta d_{t-5}$ | 0.2070 | 0.1782 | 0.2453 |
| $\Delta r_t$ | 1.5367 | 0.6748 | 0.0228 |
| $\Delta r_{t-1}$ | $-0.4469$ | 0.5813 | 0.4420 |
| $\Delta r_{t-2}$ | $-0.1175$ | 0.5948 | 0.8435 |
| $\Delta r_{t-3}$ | 0.4344 | 0.4923 | 0.3775 |
| $\Delta r_{t-4}$ | $-0.8450$ | 0.6193 | 0.1725 |
| $\Delta r_{t-5}$ | $-0.0225$ | 0.5416 | 0.9669 |
| $\Delta r_{t-6}$ | $-0.3193$ | 0.6541 | 0.6254 |
| $\Delta r_{t-7}$ | 0.8137 | 0.6968 | 0.2429 |
| $b_{t-1}$ | 0.9890 | 0.0177 | 0.0000 |
| $\sigma_{\eta_t}$ | 0.0565 | 0.0027 | 0.0000 |

Table 5: Estimation results of coefficients in stock price and bubble equation

ences of dividends and real interest rates are significant. Also the coefficient on the lagged state variable and its standard deviation are significant again. A Wald test on $H_o : \gamma = 1$ cannot reject the null. Figure 3 plots the smoothed estimate of the state variable.

The starting value of the state variable was set to zero as before. Including a time-varying interest rate eliminates the bubble in 1960s and 70s and most of the bubble in late 1990s. Also, note the negative bubble during the 1980s. This means that stock prices during that period are below what would be predicted by the present value model with a time-varying interest rate. Note however that the actual size of the bubble depends on the starting value, which is zero here. The negative bubble in the 1980s might disappear for positive starting values. Still, relevant for our purposes is that we can identify a significant stock price bubble in the late 1990s.

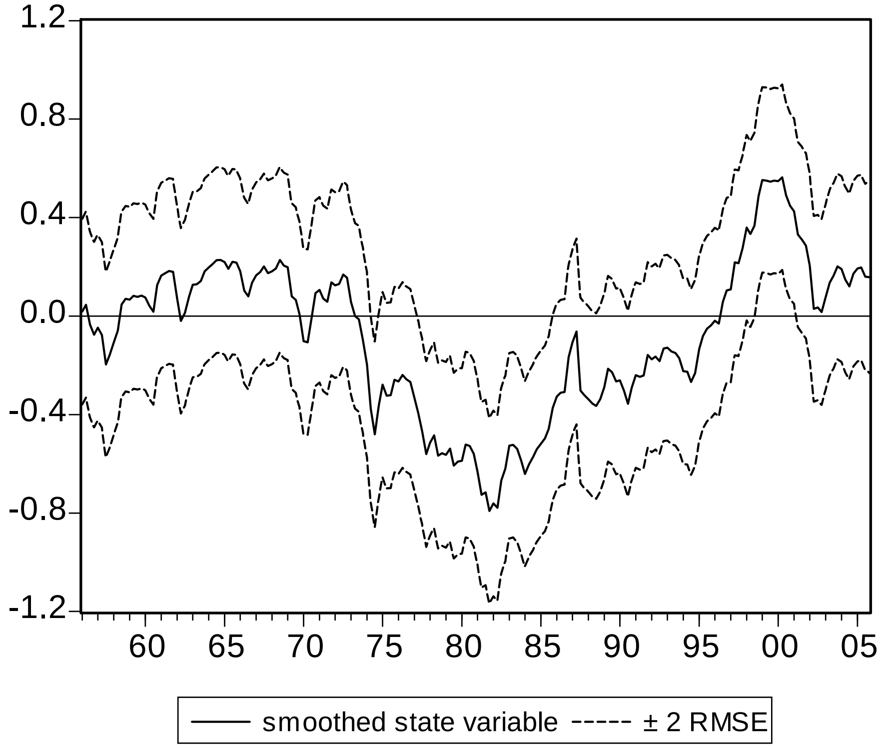


Figure 3: Smoothed estimate of state variable with 5% confidence bands

# 7 Indicators of moral hazard behaviour of investors

The main problem with analysing the empirical content of the Greenspan-put hypothesis is that moral hazard behaviour of investors is not observed. We choose the second best option and rely on theory to find indicators. In particular, we construct measures of moral hazard behaviour based on the models by Illing (2001) and Miller, Weller and Zhang (2002).

## 7.1 The probability of a stock market crash

Illing (2001) sets up a model in which the central bank wants to avoid disruption of the financial sector because this leads to a loss of informational capital and the inefficient liquidiation of solvent firms. There is one safe old economy sector and one risky new economy sector. In case of an aggregate shock to the new economy sector a share $\lambda$ of failing firms can be restructured with continuation value $C$, the share $(1 - \lambda)$ is liquidated early at the liquidation value $L$. Due to their informational capital it is only the relationship lender bank that knows which firms are worth being restructured and continued. An aggregate shock might lead to financial disruption if it triggers a bank run. Then aggregate losses would equal $\lambda(C - L)$. A bank run occurs if aggregate debt exposure is larger than what can be recovered in case of an aggregate shock. To avoid any risk of a bank run and the subsequent financial disruption, the central bank must inject enough liquidity to reduce the real value of debt. The value of real debt must equal the liquidation value of firms. The reduced real debt burden is a capital gain to the restructured firms in the new economy sector because their continuation value $C$ is now larger than their real debt burden, which equals $L$. If rational investors anticipate these capital gains they include it in the valuation of the new economy firms driving up their asset price over the fundamental value by the amount of the expected capital gain. The difference equals the asset price bubble $B_t$.

$$B_t = \xi\lambda(C - L) \tag{38}$$

where $\xi$ is the probability of an aggregate shock. The asset price bubble depends positively on the probability of an aggregate shock, the share of restructured firms and the efficiency loss avoided. We use the probability of an aggregated shock to test for moral hazard among investors. In our case $\xi$ is the probability of a stock market crash. To measure it we rely on a survey among institutional investors in the U.S. by Robert Shiller. In his Crash

Confidence Index he reports the percentage of respondents who think that the probability of a stock market crash in the following six months is less than 10%[19].

## 7.2 A minimum level of dividends

A second measure has been constructed from a theoretical model by Miller et al. (2002). They set up a continuous time model of stock prices where dividends follow a Brownian motion. The source of stock price movements over and above dividend growth are jumps in the dividend process, which are interpreted as "periodic large adverse movements which we shall term 'crises'" (Miller et al. 2002). These jumps raise the risk-premium and thus lower the stock price. However, if the central eliminates the downward jumps by providing sufficient liquidity when a fall in dividends is likely to occur, the risk-premium falls and the stock price rises. Under the assumption that investors believe that the central bank will prevent dividends from falling sharply and under various scenarios of parameter values for the real interest rate, the risk-premium, the dividend growth rate etc. Miller et al. (2002) can generate quite large stock price overvaluations of up to 204%. They assume that investors believe that the central bank will stabilise the market at some fraction $\kappa$ of the latest stock market peak $\bar{P}$. More precisely, dividends are prevented from falling below the minimum level $D_b$ which is given by

$$P\left(D_b\right) = \kappa \bar{P} \tag{39}$$

The current dividend level can be expressed as a multiple of the minimum level, $D = m\ D_b$. The stock price bubble $B$ then depends negatively on the ratio $m$ because the put option given by the central bank is worth more the

[19] For a description of the construction of the index see appendix.

closer actual dividends get to the exercise value $D_b$.

$$B = B(\underset{-}{m}) \tag{40}$$

As a measure of $m$ we use the ratio of actual dividends to their level in the period of the stock price crash in 1987 Q3[20]. This takes account of the argument that the Fed created the expecetation of a bail-out guarantee by its reaction to the Black Monday stock market crash. In addition, since the same is said to be true of the LTCM crisis in 1998, we construct an alternative measure of $m$ by letting the stock price peak in 1998 Q2 set a new peak, at 79% of which the Fed was supposed to intervene.

## 7.3 The degree of debt exposure

In addition we use the argument that a central bank's incentive to intervene in a stock market crisis rises with the degree of leverage. Illing (2001) argues that with higher leverage, i.e. the debt-gdp-ratio, the risk of a bank run and of a financial crisis rises, which in turn should lead to the build up of a bubble. Borio and Lowe (2002) present evidence in an explorative study that the deviation of the debt-gdp-ratio from its trend and the real credit growth are reasonably good predictors of financial crises. We are aware that this measure is rather weak because there might be a simultaneity problem. High credit growth might be caused by high asset price growth and vice versa. We try to avoid this problem by including only lagged values of credit growth and its deviation from trend in the tests.

## 7.4 Empirical results

There are five different indicators of moral hazard behaviour derived from the theoretical models discussed above: The probability of a stock market crash,

[20] $\kappa = 0.79$ as determined by the data.

two versions of the ratio of current dividends to a minimum level as perceived to be guaranteed by the central bank, the deviation of the debt-gdp-ratio from trend and the growth of real debt outstanding. The indicators were tested in two ways. First, we checked whether each indicator had a significant impact on the residuals from the state equation.

$$\hat{\eta}_t = \sum_{i=0}^{n} \theta_i x_{t-i} + \omega_t \tag{41}$$

where $\hat{\eta}$ are the fitted residuals from the state equation, $x_t$ is one of the different moral hazard indicators and $\omega$ is an error term. The lag length $n$ is determined by the data. Unless an indicator follows an $AR(1)$ process itself any significant influence on the bubble should show up in this test. Second, we included each indicator in turn in the measurement equation.

$$\Delta p_t = \sum_{i=0}^{5} \alpha_i \Delta d_{t-i} + \sum_{i=0}^{n} \theta_i x_{t-i} + \Delta b_t \tag{42}$$

If moral hazard behaviour had any impact on stock prices the coefficients $\theta_i$ of the indicator should be significant. One could view this specification as allowing for the part of a time-varying risk-premium, which is assumed to be influenced by the degree of moral hazard. A specification analysis of the time-series of the indicators on the basis of unit root tests, the AIC criterion and tests for autocorrelation was performed. We used the logs of the first three indicators because of the logarithmic formulation of our baseline estimation. The last two indicators are already in growth rates and deviation from trend, respectively. All indicators start in 1987 Q4 the period after the Black Monday stock market crash. Table 6 reports the results for the first test. The results across all indicators clearly reject the Greenspan-put hypothesis. None of the indicators has a significant impact on the residuals from the state equation. The only indicator that comes any close to the 10% significance level is the ratio of current dividends to the minimum level,

$\Delta \ln m_{t-i}^{1998}$, with the minimum level reset in 1998 Q4, in the period after the LTCM crisis.

Furthermore, none of the indicators has any significant impact on the log-differenced stock price in the measurement equation. The only indicator with a significance level of less than 20% is the first lag of the debt-gdp-gap. Altogether this suggests at a minimum that the predictions of the models by Illing (2001) and Miller et al. (2002) are not confirmed by the data. Under the assumption that the indicators are valid measures of moral hazard behaviour of investors, the results also indicate a clear rejection of the Greenspan-put hypothesis.

Test for misspecification of state equation (41)

$$\hat{\eta}_t = \sum_{i=0}^{n} \theta_i x_{t-i} + \omega_t$$

constant real interest rate

| indicator | lags $n$ | lag $i$ | coefficient | std. error | prob. |
|---|---|---|---|---|---|
| $\Delta \ln \xi_{t-i}$ | 0 | 0 | $-0.0062$ | 0.0143 | 0.6659 |
| $\Delta \ln m_{t-i}^{1987}$ | 0 | 0 | 0.1014 | 0.1559 | 0.5163 |
| $\Delta \ln m_{t-i}^{1998}$ | 0 | 0 | $-0.1071$ | 0.0678 | 0.1157 |
| $\frac{Debt}{GDP}$ gap$_{t-i}$ | 3 | 1 | 0.3467 | 0.8333 | 0.6777 |
| | | 2 | $-0.7472$ | 0.9809 | 0.4470 |
| | | 3 | 0.1512 | 0.8108 | 0.8523 |
| $\frac{Debt}{GDP}$ growth$_{t-i}$ | 4 | 1 | 0.2627 | 1.6023 | 0.8699 |
| | | 2 | 0.3033 | 1.6956 | 0.8581 |
| | | 3 | 0.0496 | 1.6997 | 0.9767 |
| | | 4 | $-0.4157$ | 1.6181 | 0.7975 |

time-varying real interest rate

| indicator | lags $n$ | lag $i$ | coefficient | std. error | prob. |
|---|---|---|---|---|---|
| $\Delta \ln \xi_{t-i}$ | 0 | 0 | $-0.0053$ | 0.0141 | 0.7078 |
| $\Delta \ln m_{t-i}^{1987}$ | 0 | 0 | 0.1223 | 0.1531 | 0.4254 |
| $\Delta \ln m_{t-i}^{1998}$ | 0 | 0 | $-0.0970$ | 0.0667 | 0.1472 |
| $\frac{Debt}{GDP}$ gap$_{t-i}$ | 3 | 1 | 0.0897 | 0.8140 | 0.9124 |
| | | 2 | $-0.4732$ | 0.9582 | 0.6219 |
| | | 3 | 0.1584 | 0.7920 | 0.8417 |
| $\frac{Debt}{GDP}$ growth$_{t-i}$ | 4 | 1 | $-0.1444$ | 1.5717 | 0.9269 |
| | | 2 | $-0.1870$ | 1.6627 | 0.9105 |
| | | 3 | 1.5640 | 1.6673 | 0.3494 |
| | | 4 | $-1.0938$ | 1.5872 | 0.4916 |

Table 6: Impact of moral hazard indicators on residuals from state equation

Augmented stock price equation (42)

$$\Delta p_t = \sum_{i=0}^{5} \alpha_i \Delta d_{t-i} + \sum_{i=0}^{n} \theta_i x_{t-i} + \Delta b_t$$

constant real interest rate

| indicator | lags $n$ | lag $i$ | coefficient | std. error | prob. |
|---|---|---|---|---|---|
| $\Delta \ln \xi_{t-i}$ | 0 | 0 | −0.0007 | 0.0412 | 0.9869 |
| $\Delta \ln m_{t-i}^{1987}$ | 0 | 0 | −0.3189 | 0.3132 | 0.3086 |
| $\Delta \ln m_{t-i}^{1998}$ | 0 | 0 | −0.0705 | 0.1948 | 0.7174 |
| $\frac{Debt}{GDP}$ gap | 3 | 1 | −0.4917 | 1.0179 | 0.6291 |
| | | 2 | 0.5460 | 1.4702 | 0.7103 |
| | | 3 | −0.5156 | 1.1755 | 0.6610 |
| $\frac{Debt}{GDP}$ growth | 4 | 1 | 2.4699 | 2.0581 | 0.2301 |
| | | 2 | −0.1802 | 2.4679 | 0.9418 |
| | | 3 | −0.6272 | 2.2240 | 0.7779 |
| | | 4 | −1.0684 | 3.0051 | 0.7222 |

time-varying real interest rate

| | | | | | |
|---|---|---|---|---|---|
| $\Delta \ln \xi_{t-i}$ | 0 | 0 | −0.0001 | 0.0413 | 0.9974 |
| $\Delta \ln m_{t-i}^{1987}$ | 0 | 0 | −0.3622 | 0.3812 | 0.3421 |
| $\Delta \ln m_{t-i}^{1998}$ | 0 | 0 | −0.0709 | 0.2482 | 0.7751 |
| $\frac{Debt}{GDP}$ $\text{gap}_{t-i}$ | 3 | 1 | −0.4167 | 1.0737 | 0.6979 |
| | | 2 | 0.2502 | 1.4529 | 0.8633 |
| | | 3 | −0.3448 | 1.2538 | 0.7833 |
| $\frac{Debt}{GDP}$ $\text{growth}_{t-i}$ | 4 | 1 | 2.6954 | 2.0246 | 0.1831 |
| | | 2 | −0.7397 | 2.5251 | 0.7696 |
| | | 3 | −1.4934 | 2.2285 | 0.5028 |
| | | 4 | 0.2548 | 2.9244 | 0.9306 |

Table 7: Impact of moral hazard indicators on stock prices in measurement equation

# 8 Conclusion

The research objective of this paper is to investigate the empirical content of the Greenspan-put hypothesis. It claims that investors believed in an implicit bail-out guarantee by the Fed should the stock market crash. The Fed is believed to inject liquidity into the market in a stock market crash as it has done a number of times in the past and as Greenspan (2004) claims to have done. This is supposed to have contributed to the build-up of the bubble in the late 1990s. Using the present value model of stock prices we have identified an unobserved variable which is integrated of order one as a determinant of stock prices from 1950 to 2005. Since periodically collapsing bubbles might appear integrated of order one or zero (Evans 1991) we have estimated a state-space model and have identified periods of significant estimates of the unobserved time-series component which we take as a bubble. One is during the 1960s through the early 1970s and the other one in the late 1990s. This allows to test for various measures of moral hazard behaviour of investors. These measures are constructed on the basis of theoretical models because moral hazard itself is not observable. Our results show that none of the moral hazard indicators has any explanatory power in either the bubble process itself or the stock price equation. The bubble in the late 1990s can't be explained by measures of moral hazard. However, we find that a large part of the bubble can be explained by time variations in the real interest rate.

One criticism of our approach might be that the measures of moral hazard are false. However, the measures are based on theory and thus, at a minimum, we are able to reject the predictions of the models by Illing (2001) and Miller et al. (2002). Moreover, there is the so-called Peso problem: Rational expectations of some event, like a future tax cut, might have pushed up stock prices, even though the expected event didn't materialize later on. Since these expectations are not observed and it is very hard to find a measure based on theory, we can't control for them.

All in all we are unable to confirm the conjecture of leading economists in academia and the media that there existed a Greenspan put option. It seems there is no reason to critise Alan Greenspan for having contributed to the bubble in the late 1990s. On a wider scale, our findings weaken the arguments by the advocates of a "leaning against the wind" strategy. U.S. investors obviously didn't believe in an implicit bail-out guarantee after having observed the Fed's rescue operations in the past.

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# 9 Appendix

## 9.A Unit root and cointegration tests with a time-varying interest rate

ADF regression in log-levels

$$\Delta y_t = \mu + \gamma t + \rho y_{t-1} + \sum_{i=1}^{n} \beta_i \Delta y_{t-i} + \epsilon_t$$

$H_o : \rho = 0$, unit root in $y_t$

$T = 224$ for $p_t$ and $d_t$, $T = 207$ for $r_t$

| $y_t$ | $p_t$ | $\Delta p_t$ | $d_t$ | $\Delta d_t$ | $r_t$ | $\Delta r_t$ | $\binom{p_t}{d_t}$ |
|---|---|---|---|---|---|---|---|
| | | $\gamma = 0$ | | $\gamma = 0$ | $\gamma = 0$ | $\gamma = 0$ | $\gamma = 0$ |
| n$^o$ of lags | 2 | 1 | 5 | 5 | 7 | 7 | 5 |
| t-statistic on $\rho$ | $-0.986$ | $-13.717^*$ | $-2.091$ | $-17.063^*$ | $-0.718$ | $-9.897^*$ | $-1.959$ |
| 5% critical value | $-3.423$ | $-2.876$ | $-3.423$ | $-2.876$ | $-2.876$ | $-2.876$ | $-3.380$ |

Table 8: ADF unit root and cointegration tests on the natural logarithm of the real stock price, dividends and the real interest rate

Table 8 presents the results for unit root tests on the present value model with a time-varying interest rate. The fact that the real interest rate seems integrated of order 1 in table 8 is probably due to a structural break at the beginning of the 1980s when inflation fell sharply due to Paul Volcker's tight monetary policy and the real interest rate soared. For the purpose of our analysis we disregarded formally checking and accounting for a structural break in the unit root tests because our conclusions don't depend on it.

## 9.B Bhargava (1986) test statistics

For the null hypothesis of a simple random walk against the stationary alternative:

$$R_1 = \frac{\sum_{t=2}^{T} \left(y_t - y_{t-1}\right)^2}{\sum_{t=1}^{T} \left(y_t - \bar{y}\right)^2} \tag{43}$$

where $\bar{y}$ is the sample average. Reject if $R_1$ larger than critical value.

For the null hypothesis of a random walk with drift against the stationary alternative:

$$R_2 = \frac{\sum_{t=2}^{T} \left(y_t - y_{t-1}\right)^2 - \frac{1}{T-1}\left(y_T - y_1\right)^2}{\frac{1}{(T-1)^2} \sum_{t=1}^{T} \left[(T-1)\, y_t - (t-1)\, y_T - (T-t)\, y_1 - (T-1)\left(\bar{y} - \frac{1}{2}\left(y_1 + y_T\right)\right)\right]^2} \tag{44}$$

Reject if $R_2$ larger than critical value.

For the null hypothesis of a simple random walk against the explosive alternative:

$$N_1 = \frac{\sum_{t=2}^{T} \left(y_t - y_{t-1}\right)^2}{\sum_{t=2}^{T} \left(y_t - y_1\right)^2} \tag{45}$$

Reject if $N_1$ smaller than critical value.

For the null hypothesis of a random walk with drift against the explosive alternative:

$$N_2 = \frac{\sum_{t=2}^{T} \left(y_t - y_{t-1}\right)^2 - \frac{1}{T-1}\left(y_T - y_1\right)^2}{\frac{1}{(T-1)^2} \sum_{t=1}^{T} \left[(T-1)\, y_t - (t-1)\, y_T - (T-t)\, y_1\right]^2} \tag{46}$$

Reject if $N_2$ smaller than critical value.

## 9.C Shiller's crash confidence index

Survey data on investors' stock market confidence has been collected since 1984 by Robert Shiller within the Investor Behavior Project at the Yale International Center for Finance. The questionnaire has been sent to a number of U.S. investors who have been sampled from the investment managers section of the Money Market Directory of Pension Funds and Their Investment Managers. The average sample size in each survey round has been about a hundred. From the data several indices relating to different aspects of stock market confidence are constructed, among them the percentage of respondents who think that the probability of a stock market crash in the following six months is less than 10%. The exact wording of the question in the questionnaire is:

> What do you think is the probability of a catastrophic stock market crash in the U. S., like that of October 28, 1929 or October 19, 1987, in the next six months, including the case that a crash occurred in the other countries and spreads to the U. S.? (An answer of 0% means that it cannot happen, an answer of 100% means it is sure to happen.)
>
> Probability in U. S.:________________%

More on the methodology of Shiller's stock market crash confidence index can be found on *http://icf.som.yale.edu/confidence.index/CrashIndex.shtml.* The crash confidence index is available from October 1989 until July 2001 at semi-annual frequency and thereafter at monthly frequency. Given the quarterly frequency of our main sample we converted the index from October 1989 to July 2001 to quarterly data by interpolation and thereafter by averaging.