Explosive Behavior in the 1990s Nasdaq:

When Did Exuberance Escalate Asset Values?

Fundamental and Non-Fundamental Asset Pricing Dynamics
Venastul, Norway

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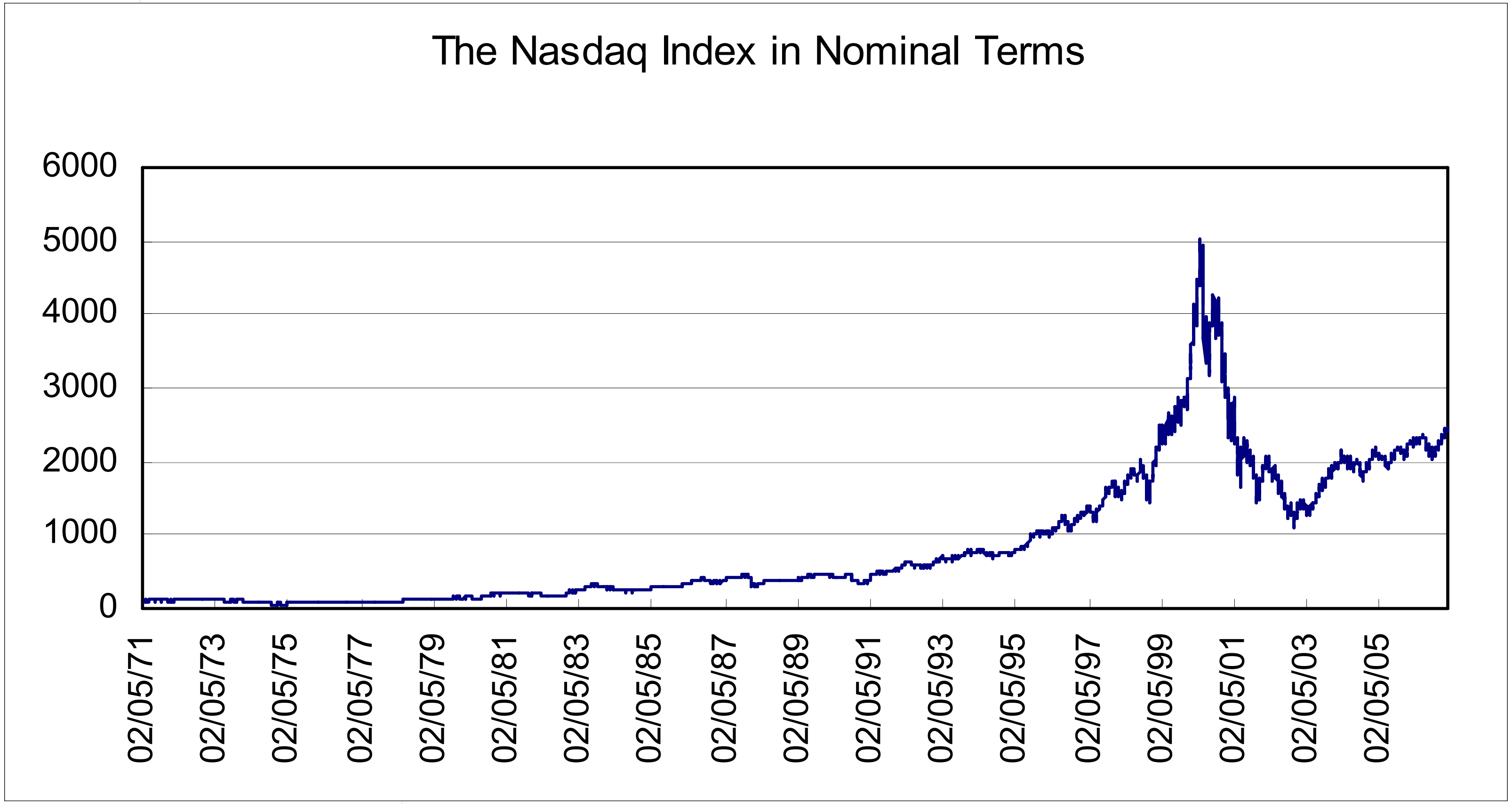
Outline of Presentation

I. Motivations and summary of contributions
II. Model specification and empirical strategy
III. Testing for and dating the Nasdaq bubble
IV. Finite sample analysis
V. Conclusion

I. Motivations and Summary of Contributions



I. Motivations and Summary of Contributions (2)

I. Motivations and Summary of Contributions (3)

- "How do we know when irrational exuberance has unduly escalated asset values?" (Alan Greenspan, 12/5/1996)

- "Experience can be a powerful teacher. The rise and fall of internet stocks, which created and then destroyed $8 trillion of shareholder wealth, has led a new generation of economists to acknowledge that bubbles can occur." (Alan Krueger, New York Times, 4/29/2005)

I. Motivations and Summary of Contributions (4)

- Stock market bubble: important issue.
- The Nasdaq index was 329.80 on 10/31/1990, but climbed to 5048.62 on 3/10/2000, with an average annual return of 31%.
- The internet stocks created and then destroyed $8 trillion of shareholder wealth in the 1990s.
- The question of whether there was a bubble in the 1990s has attracted much attention of policy makers, practitioners, academicians and the general public.
- A partial list of references includes Greenspan (1996), Shiller (2000), Ofek and Richardson (2002), Rittar and Warr (2002), Pastor and Veronesi (2006), etc.
- The remark of "irrational exuberance" by Greenspan on December 5, 1996 is the most celebrated and remains the most oft-quoted.

I. Motivations and Summary of Contributions (5)

- While casual observations suggest the existence of a Nasdaq bubble, there is no consensus especially among academicians.
- The real issues still remain outstanding:
- Do we really know it?
- Can we date it?
- How fast does a bubble grow?
- How much confidence do we have?

I. Motivations and Summary of Contributions (6)

- What we do in this paper:
- Empirically examine the Nasdaq market performance in relation to the perceptions of bubble behavior by Alan Greenspan and other commentators.
- Did Greenspan foresee the outbreak of a bubble in his perception of growing market exuberance and its dangers, or was his perception of herd behavior supported by empirical evidence of an ongoing bubble characteristic in the data?
- To achieve this goal, we introduce some new econometric methodology based on forward recursive regression. Our approach utilizes some new machinery that permits the construction of valid asymptotic confidence intervals for explosive processes and tests of explosive characteristic in time series data.

I. Motivations and Summary of Contributions (7)

- We find strong explosive behavior in the Nasdaq in the 1990s.
- We demonstrate that exuberance started in June 1995, thereby predating and providing empirical content to the Alan Greenspan remark in December 1996.
- The bubble peaked in February 2000 and collapsed in August 2001.
- Simulation results show that our tests perform well in finite samples calibrated to the Nasdaq data.

II. Methodology

- Most tests begin with the standard present value model

$$P_t = \frac{1}{1+R} E_t(P_{t+1} + D_{t+1})$$

- Following Campbell and Shiller (1989), we take the log-linear approximation

$$\gamma = \kappa + \rho E_t p_{t+1} + (1-\rho) E_t d_{t+1} - p_t$$

- where an upper case letter denotes the level of a variable and a lower case letter denotes the natural log of a variable.

II. Methodology (2)

- Solving the above difference equation yields:

$$p_t = p_t^f + b_t$$

where

$$p_t^f = \frac{\kappa - \gamma}{1-\rho} + (1-\rho)\sum_{i=0}^{\infty} \rho^i E_t d_{t+1+i}$$

$$b_t = \lim_{i\to\infty} \rho^i E_t p_{t+i}$$

$$E_t(b_{t+1}) = \frac{1}{\rho} b_t, \quad \frac{1}{\rho} > 1$$

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II. Methodology (3)

- The above implies that

$$
\begin{aligned}
b_t &= \frac{1}{\rho} b_{t-1} + \varepsilon_{b,t} \\
&\equiv (1+g) b_{t-1} + \varepsilon_{b,t}
\end{aligned}
$$

$$g > 0$$

$$E_{t-1}(\varepsilon_{b,t}) = 0$$

- Notice that this process is completely consistent with the no-arbitrage condition and hence the bubble is so-called "*rational*". Many papers provide theoretical justifications for the existence of a rational bubble, see Tirole (1982, 1985, *Econometrica*), among others.

II. Methodology (4)

- In the absence of a bubble, i.e., $b_t = 0, \forall t$, we will have $p_t = p_t^f$
- The stochastic behavior of p_t will be entirely determined by p_t^f and hence by dividends.
- In this case, we have

$$d_t - p_t = -\frac{\kappa - \gamma}{1-\rho} - \sum_{i=0}^{\infty} \rho^j E_t(\Delta d_{t+1+i})$$

- Therefore, if the stock price and dividend series are both I(1), they should be cointegrated with the cointegrating vector [1,-1].

II. Methodology (5)

- If there is a bubble, an explosive behavior of the bubble implies an explosive behavior of price, irrespective of whether the dividend process is I(1) or I(0). In this case, the first difference of price is also explosive and cannot be stationary. This is the motivation for unit root and cointegration tests for bubbles in Diba and Grossman (1988 *AER*).

- Evans (1991 *AER*) questions the validity of the Diba and Grossman test by arguing that none of these tests have power to detect periodically collapsing bubbles.

II. Methodology (6)

- We suggest testing for an explosive root in price and dividend directly

$$x_t = \mu + \delta x_{t-1} + \sum_{j=1}^{J} \varphi_j \Delta x_{t-j} + \varepsilon_{x,t}$$

- where x is either price or dividend.

$$H_0 : \delta = 1$$

$$H_1 : \delta > 1$$

- A sufficient condition for the existence of a bubble is that the price process is explosive and the dividend process is not. Dividend can be either I(1) or I(0).

II. Methodology (7)

- Empirically it is extremely difficult to reject the null in favor of the alternative of explosiveness.

- Campbell, Lo, MacKinlay (1997, p.260) summarize that "…empirically there is little evidence of explosive behavior" in stock price.

- To overcome the power issue, we implement the sup ADF_r test and the forward recursive test.

- In forward recursive regressions, the above equation is estimated repeatedly, using subsets of sample data incremented by one observation at each pass.

II. Methodology (8)

- Finite sample bias correction via indirect inference estimation (Gourieroux et al, 1993, 2000, 2005)

$$\hat{\delta}^{II}_{n,H} = \arg\min_{\delta \in \Phi} \left\| \hat{\delta}^{LS}_{n} - \frac{1}{H} \sum_{h=1}^{H} \tilde{\delta}^{h}_{n}(\delta) \right\|$$

where $\tilde{\delta}^{h}_{n}(\delta)$ is the LS estimator based on the h^{th} simulated path given the true δ

Asymptotic confidence interval can be constructed as

$$\left(\hat{\delta}^{II}_{n,H} \pm \frac{(\hat{\delta}^{II}_{n,H})^2 - 1}{(\hat{\delta}^{II}_{n,H})^n} C_\alpha \right)$$

where C_α is the 2-tailed α percentile critical value of the standard Cauchy distribution.

III. Testing for and Dating the Nasdaq Bubble:

Data Source

- From *Datastream International:* Nasdaq prices and dividends.
- From St. Louis Fed: Consumer Price Index (CPI).
- Sample period: February 1973 to June 2005, with 389 monthly observations.

III. Testing for and Dating the Nasdaq Bubble:

Full Sample Results, Table 1

- Standard ADF_1 test finds no explosive behavior in either price or dividend. Based on these results, one may conclude that there is no evidence of bubble. This is not surprisingly as the test is subject to Evans's criticism.

- Sup ADF_r test shows strong evidence of explosive behavior in price, but not in dividend series, thereby suggesting existence of a bubble.

Table 1 Testing for a bubble in Nasdaq Index: 1973.2-2005.6

	ADF_1	Sup ADF_r
Log price	-0.826	2.894
Log dividend	-1.348	-1.018
Critical values for explosive alternative		
1 percent	0.60	2.094
5 percent	-0.08	1.468
10 percent	-0.44	1.184

III. Testing for and Dating the Nasdaq Bubble:

Dating the Bubble, Figure 2

- Figure 2 locates the origin and conclusion of the bubble based on forward recursive regressions.
- Dividend is always non-explosive.
- We find a bubble starting in June 1995, 18 months before Greenspan made his historical remark of "irrational exuberance" in December 1996.
- Evidence in support of a bubble becomes stronger from this point on and peaks in February 2000. The bubble continued until July 2001. By August 2001, there is no longer evidence of a stock bubble.

Figure 2: Time Series Plot of Test Statistics 1976.5 to 2005.6

III. Testing for and Dating the Nasdaq Bubble: Results in the 1990s, Table 2 and Figure 3

- January 1990–December 1999, the decade data used by many researchers.
- Strong evidence of bubble.
- Bubble started June 1995, same as before using full sample.
- Bubble ended October 2000, somewhat earlier than previous results using full sample.
- Indirect inference estimate yields a g =3.3% growth rate per month in price.
- Assume the Nasdaq was 10% over-valued when Greenspan made his remark in December 1996. By March 2000 when the Nasdaq reached its historic high, the expected bubble and price would be

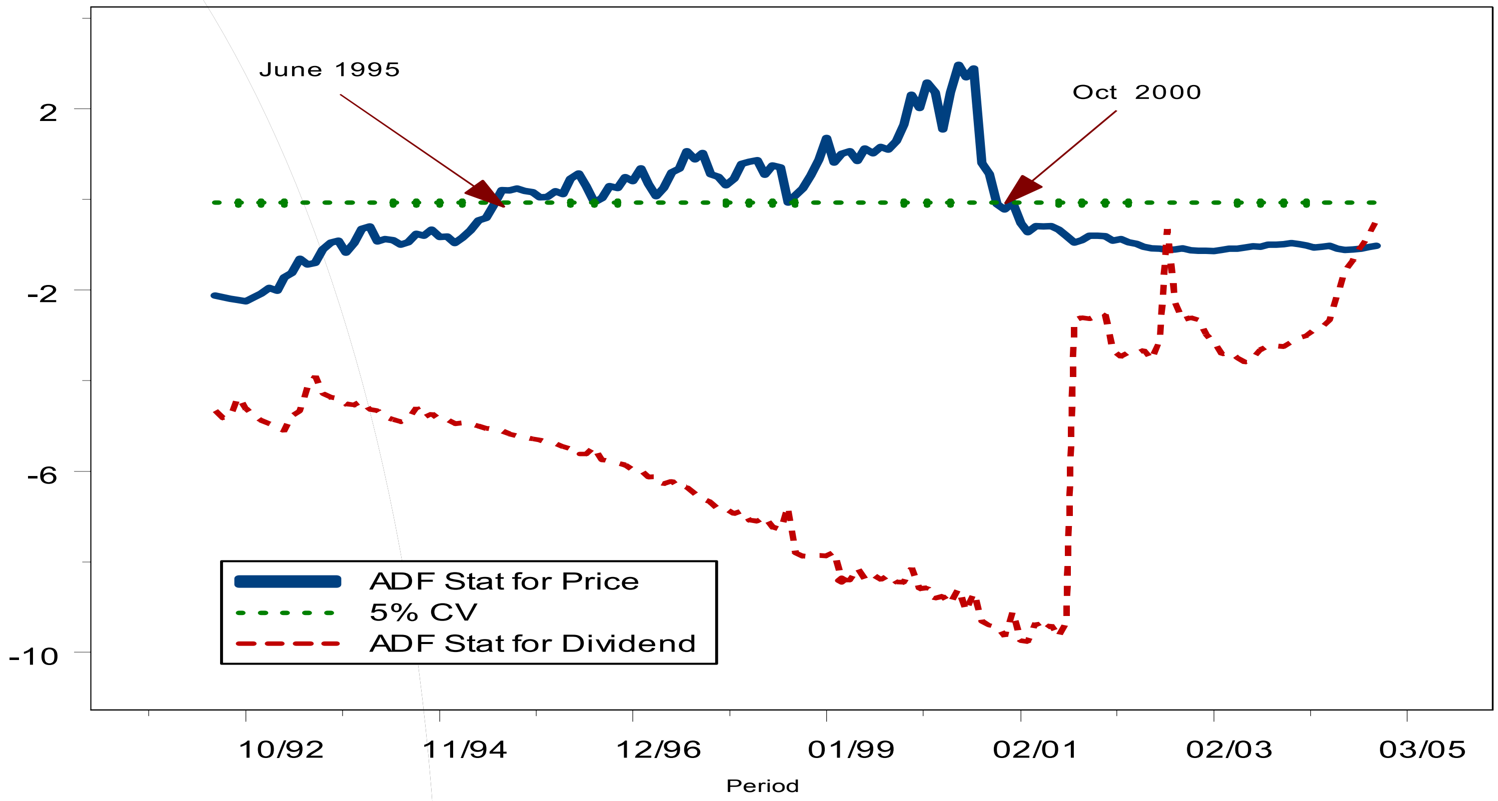
$$b_t = (1+0.033)^{39} \times \log(1.10) = 0.338$$

$$\frac{P_t}{P_t^f} = \exp(b_t) = \exp(0.338) = 1.40$$

Table 2 Testing for a Bubble in the Nasdaq in the 1990s

	ADF_1	Sup ADF_r	δ^{LS}	δ^{II}	95% CI
1990.1-1999.12					
Log price	2.309	2.894	1.025	1.033	[1.016, 1.050]
Log dividend	-8.140	-1.626	0.258		
1990.1-2000.6					
Log price	2.975	2.975	1.036	1.040	[1.033, 1.047]
Log dividend	-8.600	-1.626	0.204		

Figure 3: Time Series Plot of Test Statistics 1991.6 to 2005.6



III. Testing for and Dating the Nasdaq Bubble:

Sharper Estimate of Growth Rate Using Data January1990 – June 2000

- The above is only a *lower bound* estimate.
- A sharper estimate of the speed of explosion for bubble using observations from January 1990 – June 2000.
- Indirect inference estimate yields a g =4.0% growth rate per month in price.
- Assume the Nasdaq was 10% over-valued when our test first detected the bubble to start in June 1995. By June 2000 (60 months later) when our test detected the bubble to be the strongest, the expected bubble and price would become

$$b_t = (1 + 0.04)^{60} \times \log(1.10) = 1.0025$$

$$\frac{P_t}{P_t^f} = \exp(b_t) = \exp(1.0025) = 2.73$$

- Or the index would be 173% over-priced relative to its “fundamental”.

III. Testing for and Dating the Nasdaq Bubble:

Do These Estimates Make Sense?

- The Nasdaq peaked at 5,048.62 on March 10, 2000;
- then dropped to
- 1,950.4 by December 31, 2001;
- 1,335.31 by December 31, 2002.

- If the year 2001 end value is considered close to the "fundamental" value, then it would be 159% over-valued at the peak (5049/1950=2.59).

- If the year 2002 end value is considered close to the "fundamental" value, then it would be 278% over-valued at the peak (5049/1335=3.78).

IV. Finite-Sample Analysis:

Linear Bubble Process

- Power of test for a linear bubble process

$$p_t = p_t^f + b_t$$

$$p_t^f = \mu_f + p_{t-1}^f + \varepsilon_{f,t}$$

$$b_t = (1+g)b_{t-1} + \varepsilon_{b,t}$$

- Use observations from 1973.2-1989.12 to estimate fundamental process assuming there was no bubble during that period.
- Then use these parameters, along with g = 0.04 to estimate the bubble innovation parameter using observations from 1990.1-2000.6 via Kalman filter, as in Wu (1997).

Table 3 Power of ADF_1 Test: Panel A

Initial value b_0	g=0.00	g= 0.01	g=0.02	g=0.03	g=0.04
0.00	0.049	0.107	0.458	0.806	0.934
0.02	0.049	0.111	0.464	0.810	0.937
0.04	0.049	0.115	0.476	0.818	0.935
0.06	0.049	0.119	0.495	0.828	0.951
0.08	0.049	0.125	0.522	0.848	0.954
0.10	0.049	0.134	0.550	0.866	0.961

Table 3 Power of ADF_1 Test: Panel B

Initial value b_0	$\sigma_b = 0.005$	$\sigma_b = 0.01$	$\sigma_b = 0.02$	$\sigma_b = 0.03$	$\sigma_b = 0.04$
0.00	0.652	0.817	0.901	0.930	0.942
0.02	0.822	0.851	0.905	0.933	0.944
0.04	0.972	0.911	0.924	0.934	0.948
0.06	0.999	0.962	0.936	0.945	0.950
0.08	1.000	0.988	0.953	0.952	0.955
0.10	1.000	0.998	0.968	0.961	0.961

IV. Finite-Sample Analysis:

Periodically Collapsing Bubble

- Evans (1991) suggests the following periodically collapsing bubble process

$$B_{t+1} = (1+g)B_t\varepsilon_{b,t+1}, \text{ if } B_t \le \alpha$$

$$B_{t+1} = [\varsigma + \pi^{-1}(1+g)\theta_{t+1}(B_t - (1+g)^{-1}\varsigma)]\varepsilon_{b,t+1}, \text{ if } B_t > \alpha$$

- where θ_t is a Bernoulli process

$$\theta_t = \begin{cases} 1, & \text{prob} = \pi \\ 0, & \text{prob} = 1-\pi \end{cases}$$

- and the fundamental process is

$$D_t = \mu_D + D_{t-1} + \varepsilon_{d,t}$$

$$P_t^f = \mu_D(1+g)g^{-2} + D_t / g$$

Table 4 Power of ADF_1 and Sup ADF_r Tests under the Evans Model

π	0.999	0.99	0.95	0.85	0.75	0.50	0.25
ADF_1	0.914	0.460	0.069	0.022	0.016	0.026	0.044
Sup ADF_r	0.992	0.927	0.714	0.432	0.351	0.342	0.340

IV. Finite-Sample Analysis:
An Alternative Model of Periodically Collapsing Bubble

- We propose the following bubble process

$$B_{t+1} = (1+g)B_t\varepsilon_{b,t+1}, \text{ if } B_t \le \alpha$$
$$B_{t+1} = [\varsigma + \pi^{-1}(1+g)\theta_{t+1}(B_t - (1+g)^{-1}\varsigma)]\varepsilon_{b,t+1}, \text{ if } B_t > \alpha$$

- where

$$\theta_t = \begin{cases} 1, & \text{if } S_{t+1} > \nu_n \\ 0, & \text{if } S_{t+1} \le \nu_n \end{cases}$$

$$S_t = \sum_{l=1}^{t} \xi_l$$

S_t is an index measuring the strength of cognitive bias underlying herd behavior in the market.

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Table 5 Power of ADF_1 and Sup ADF_r Tests under the Alternative Bubble Model: 100 Observations

v/σ_ξ	-0.3	-0.2	-0.15	-0.1
ADF_1	0.346	0.305	0.339	0.350
Sup ADF_r	0.672	0.595	0.638	0.730

Table 6 Power of ADF_1 and Sup ADF_r Tests under the Alternative Bubble Model: 400 Observations

v/σ_ξ	-0.3	-0.2	-0.15	-0.1
ADF_1	0.416	0.390	0.376	0.322
Sup ADF_r	0.847	0.794	0.807	0.826

V. Conclusion

- We provide decisive evidence of explosive behavior in the 1990 Nasdaq.
- We find the bubble origination date to be June 1995, the peak in February 2000, and the collapse in August 2001.
- The origination date we found is 18 months prior to Alan Greenspan's historical remark. Greenspan's perception of herd behavior is supported by empirical evidence of an ongoing bubble characteristic in the data.
- Methodologically, we propose a new approach to testing for explosiveness which is interesting on its own right.
- Simulations reveal that the approach works well in finite samples and has discriminatory power to detect explosive processes and periodically collapsing bubbles.