Cointegration Among Stock Bubbles, Inflation and Output: A NARDL Approach

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This article investigates the relationship among stock bubbles, inflation and output. Following preceding studies, asymmetric effect should be considered with the presence of stock market. The test utilizes non-linear autoregressive distributed lag (NARDL) model. The model fits better to the bubbles rather than fundamentals, and cointegrations are found in both models. The asymmetric effect only appears in fundamentals. Combining with monetary policies in the U.S., conclusion is made that the stock prices tend to be mispriced when inflation and output drop.

Keywords: Asymmetric Effect, Cointegration, Macroeconomics, Stock Bubble, Inflation, Output

Introduction

The pattern of stock prices and the relationship between security markets and macroeconomic movement are always intriguing topics for monetary and financial economists. In the field of economics, stock prices are claims for future earnings of firms, which explicitly reflect the market expectation to future productivity of an economy. In reality, stock prices are highly volatile and the market persists some anomalies. That is, stock prices may be mispriced by the market. The essence of stock price is therefore divided into fundamental and bubble. The former is the "real value" of stock, and the latter is the "mispriced" part. In this article, I aim to investigate the cointegration among stock bubbles and macroeconomic factors, specifically inflation and output.

The researches regarding the relationship between stock and inflation start early. Fisher, 1930 proposed that stocks can be a hedge against inflation. Hence, in this classical view, stock returns should be positively related to inflation. Nevertheless, several empirical studies in 1970s did not conform to this perspective. To name a few, Nelson, 1976, Fama and Schwert, 1977, Schwert, 1981 had found negative correlation between stock returns and inflation in post-war data. Fama and Schwert, 1977 implemented expected and unexpected inflation as separate inde-pendent variables rather than actual inflation in the former studies. The separation can also be seen in Fama, 1981.

To explain such negative correlation, Fama, 1981 argued that the correlation itself is spurious. To be more specific, he considered the correlation is the aftermath of proxying the positive correlation between stock returns and real activity. This is known as “Fama’s proxy hypothesis”. The statistical model indicates that the negative correlation is largely induced when involving real activity and money supply in the model. However, the hypothesis was later argued by several studies such as Geske and Roll, 1983 and Ely and Robinson, 1992.

In more recent studies, the empirical evidences of the relationship between inflation and stock market start to vague. Studies may contradict to each other due to the selected method, periods, and variables. Kim and Ryoo, 2011 found strong evidence in the hedge effect stock has on inflation in U.S. with two-regime vector error correction model (VECM). Alagidede and Panagiotidis, 2012 empolyed GARCH filter, finding the similar result in G7 countries except for Canada. Furthermore, Tiwari et al., 2011 implemented wavelet analysis to this topic, concluding that the comovement between stock and inflation is weak in short-term while strong in long term, but the causality between the two is depending on the causality test itself.

On the other hand, there are studies that find negative relation between stock and inflation. Valcarcel, 2012 suggested a weak correlation between stock prices and inflation with time-varying structural VAR. Antonakakis et al., 2017 utilized DCC-GARCH model on U.S. data, resulting in negative relation between stock and inflation except for few periods. Alqaralleh, 2020 argued that the asymmetric effect between inflation and stock return causes any symmetric model result in spurious regression. Alqaralleh, 2020 implemented non-linear autoregressive distributed lag (NARDL) model to capture the asymmetric effect, concluding that inflation reduces stock return more in contractionary time than it does in expansionary times.

The model in this article follows Alqaralleh, 2020. Since non-linearity was found in the return case, the model for bub-

Table 1

The retrieved data and sources.

Notation	Variables	Access Period	Frequency	Source
$CAPE_t$	CAPE ratio	1990 to 2020	Monthly	Robert Shiller Online Data
inf_t	Inflation	2000 to 2020	Monthly	FRED
ipi_t	Industrial Production Index	2000 to 2020	Monthly	FRED

ble and fundamental should consider asymmetric effect as well. The first part of this article is the introduction. The second part is the description of data and statistical framework. In the third part, the statistical result shall be presented. Finally, in the forth part, a conclusion will be made.

Data and Framework

Data Retrieving

The bubbles of S&P 500 in this article are measured by transformation of cyclic adjusted PE ratio (CAPE) purposed by Campbell and Shiller, 1998. The transformation method will be introduced in the next subsection. Monthly inflation is measured by the continuous compounded rate of change of consumer price index for all urban consumers: all items in U.S. city average, and monthly output is measured by industrial production: total index. The sources of data is presented in table 1.

Bubbles Identification

The identification of stock bubbles is always a major challenge in economics. Considering the interest rate, Galí, 2014 and Galí and Gambetti, 2015 argued that increase in interest rate gives rise of stock bubbles. Though the theoretical construction is not controversial, the empirical result was later challenged by papers such as Beckers and Bernoth, 2016 and Arias et al., 2018. Therefore, Evgenidis and Malliaris, 2020 proposed a sophisticated method to extract the bubble components in practice. First they consider the 10-year moving average of the year, and define the threshold as the 10-year moving average of CAPE plus 1.5 times that 10-year standard deviation. The bubble is measured by subtracting the threshold from the actual CAPE ratio. The number 1.5 was chosen since this generates compatible overpriced and underpriced periods. Evgenidis and Malliaris, 2020 computed the bubbles from 1960 to 2016 and find the result consistent with Philips et al., 2015. It is worth-mentioning that Philips et al., 2015 do not consider the financial crisis in 2008 as a consequence of bubble expansion. The computed thresholds and the bubbles can be seen in figure 1 and 2.

Let $mbub := \min_t\{bub_t\} - 1$, and define $rbub_t := \ln(bub_t - mbub) - \ln(bub_{t-1} - mbub)$. Since there are non-positive values in bub_t, I use $mbub$ to make log difference applicable. On the other hand, since all observations of $funt_t$ are positive, definition of $rfund_t := \ln fund_t - \ln fund_{t-1}$ is trivial. The descriptive statistics of the data is presented in table 2. The relationship among inf_t, $rbub_t$ and $rfund_t$ is demonstrated in figure 3. From the figure the expectation of cointegration between bubbles growth and inflation can be made. However, as the volatility of fundamental growth is small, it may be difficult to explore any relationship.

Figure 1

The actual CAPE and the threshold

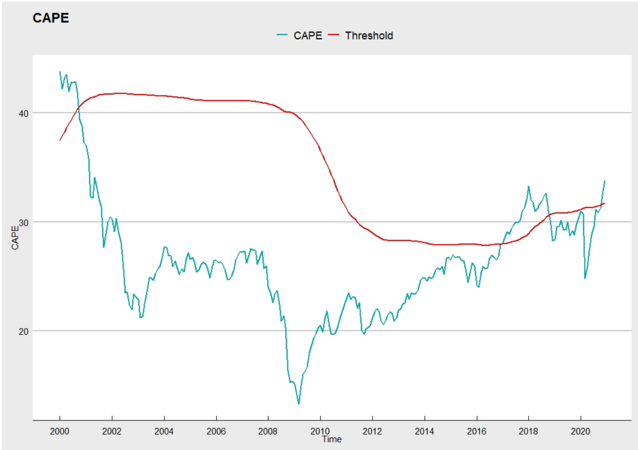


Figure 2

The measurement of bubbles

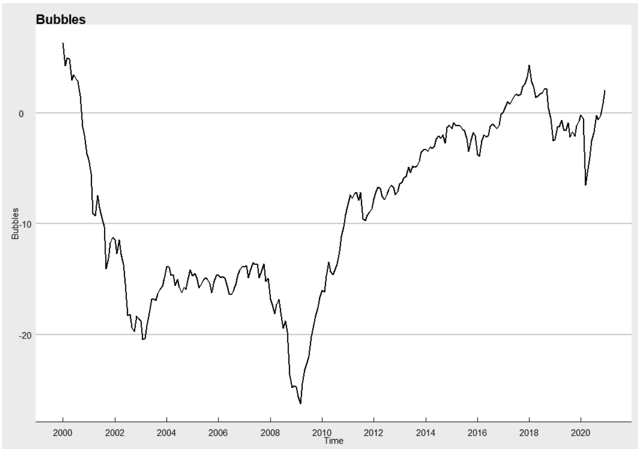


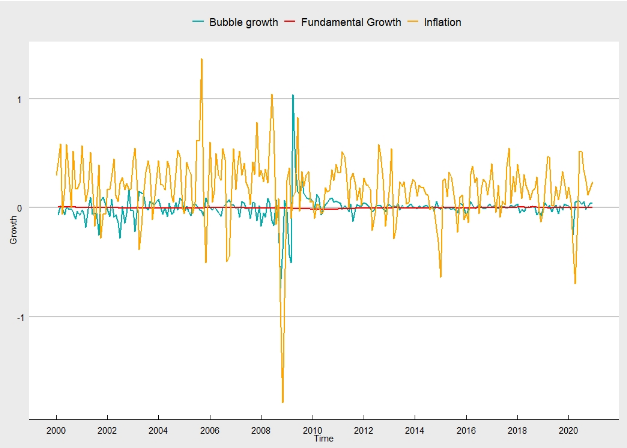
Table 2

Moments of data

Notation	Variables	Mean	Standard Deviation	Skewness	Kurtosis
$CAPE_t$	CAPE ratio	26.2890	5.3447	0.8415	4.8698
bub_t	Bubble	-8.6156	7.7059	-0.1295	1.8880
$rbub_t$	Bubble Growth	-5.432e-4	0.1170	1.1830	35.1067
$funt_t$	Fundamental	34.9046	5.8511	-2.644e-3	1.1688
$rfund_t$	Fundamental Growth	-6.611e-4	4.384e-3	-0.9359	5.5207
inf_t	Inflation	0.1738	0.2935	-1.3340	12.1895
ipi_t	Industrial Production Index	96.4907	4.8863	-0.4035	2.1249

Figure 3

Bubbles, fundamentals and inflation



Statistical Framework

As proposed by Alqaralleh, 2020, the asymmetric effect should be considered with the presence of stock market. Investigation of asymmetric effects can be realized by implementation of NARDL developed by Shin et al., 2014. My model follows Alqaralleh, 2020, but with different dependent variables: bubbles and fundamentals of S&P 500 index. The model of bubbles is defined as

$$\begin{aligned}\Delta rbub_t &= \beta_0 + \rho rbub_{t-1} + \varphi_1^+ inf_{t-1}^+ + \varphi_1^- inf_{t-1}^- \\ &+ \varphi_2^+ ipi_{t-1}^+ + \varphi_2^- ipi_{t-1}^- + \sum_{i=1}^{p-1} \beta_i \Delta rbub_{t-i} \\ &+ \sum_{i=0}^{q-1} (\delta_i^+ \Delta inf_{t-i}^+ + \delta_i^- \Delta inf_{t-i}^- + \lambda_i^+ \Delta ipi_{t-i}^+ + \lambda_i^- \Delta ipi_{t-i}^-) \\ &+ u_t \qquad (1)\end{aligned}$$

where $\Delta x_t^+ := \max\{\Delta x_t, 0\}$, $\Delta x_t^- := \min \Delta x_t, 0$, $x_t^+ := \sum_{i=1}^t \Delta x_i^+$ and $x_t^- := \sum_{i=1}^t \Delta x_t^-$ $\forall x \in \{inf, ipi\}$. ρ evaluates the strength of error correction (if it is negatively signed and of significance), $\varphi_j^k \, \forall j \in \{1,2\}, k \in \{+,-\}$ evaluates the long term relation, and $\delta_i^k, \lambda_i^k \, \forall i \in \{1,2,...,q-1\}, k \in \{+,-\}$ evaluates short run relation.The optimal lag of $(p,q) = (6,8)$ is determined by AIC criterion. The model of fundamental remains similar. To make the model compatible, we use the same (p,q) for fundamental model. The only difference of the two models is the dependent variable.

$$\begin{aligned}\Delta rfund_t &= \beta_0 + \rho rfund_{t-1} + \varphi_1^+ inf_{t-1}^+ + \varphi_1^- inf_{t-1}^- \\ &+ \varphi_2^+ ipi_{t-1}^+ + \varphi_2^- ipi_{t-1}^- + \sum_{i=1}^{p-1} \beta_i \Delta rfund_{t-i} \\ &+ \sum_{i=0}^{q-1} (\delta_i^+ \Delta inf_{t-i}^+ + \delta_i^- \Delta inf_{t-i}^- + \lambda_i^+ \Delta ipi_{t-i}^+ + \lambda_i^- \Delta ipi_{t-i}^-) \\ &+ u_t \qquad (2)\end{aligned}$$

Bound F test proposed by Pesaran et al., 2001 can be implemented to test the the hypothesis of

$$\begin{aligned}&\mathbb{H}_0 : \rho = \varphi_1^+ = \varphi_1^- = \varphi_2^+ = \varphi_2^- = 0 \\ &\mathbb{H}_1 : \text{at least one of } \rho, \varphi_1^+, \varphi_1^-, \varphi_2^+, \varphi_2^- \text{ is not zero} \qquad (3)\end{aligned}$$

Rejection of equation 3 can be inferred to the existence of cointegration. Pesaran et al., 2001 derived the critical values of the test. On the other hand, to test the long run asymmetry for inflation, one can consider a Wald Chi-square test with the hypothesis of

$$\begin{aligned}\mathbb{H}_0 &= \frac{-\varphi_1^+}{\rho} = \frac{-\varphi_1^-}{\rho} \\ \mathbb{H}_1 &= \frac{-\varphi_1^+}{\rho} \neq \frac{-\varphi_1^-}{\rho} \qquad (4)\end{aligned}$$

The rejection of the test imposes the asymmetric effect. Similarly, the long run asymmetry for output can be tested by

$$\mathbb{H}_0 = \frac{-\varphi_2^+}{\rho} = \frac{-\varphi_2^-}{\rho}$$
$$\mathbb{H}_1 = \frac{-\varphi_2^+}{\rho} \neq \frac{-\varphi_2^-}{\rho} \quad (5)$$

On the other hand, the short run asymmetry for inflation can be test through Wald Chi-square test with the following hypothesis.

$$\mathbb{H}_0 : \sum_{i=1}^{q-1} \delta_i^+ = \sum_{i=1}^{q-1} \delta_i^-$$
$$\mathbb{H}_1 : \sum_{i=1}^{q-1} \delta_i^+ \neq \sum_{i=1}^{q-1} \delta_i^- \quad (6)$$

and the short run asymmetry for output can be tested by

$$\mathbb{H}_0 : \sum_{i=1}^{q-1} \lambda_i^+ = \sum_{i=1}^{q-1} \lambda_i^-$$
$$\mathbb{H}_1 : \sum_{i=1}^{q-1} \lambda_i^+ \neq \sum_{i=1}^{q-1} \lambda_i^- \quad (7)$$

The NARDL model investigates the asymmetric effect for I(0) and I(1) variables, but not for higher terms. Table 3 shows the result of ADF test (Dickey & Fuller, 1981) for each variable. According to the result, NARDL is suitable in this case.

Table 3

ADF test. Significance code: '$***$': 0.001, '$**$': 0.01, '$*$': 0.05, '.': 0.1

Variables	ADF Statistics	Inference
$rbub_t$	-11.5822***	I(0)
$rfund_t$	-2.2642**	I(0)
inf_t	-8.3288***	I(0)
ipi_t	0.1466	I(1)
Δipi_t	-11.7721***	I(0)

Result

Upon fitting the data, model diagnostics ensure that the results are effective. Breusch-Pagan test (BP test) proposed by Breusch and Pagan, 1979 is used to test heteroskedasticity, while Durbin-Watson test (DW test) proposed by Durbin and Watson, 1950 is used to test serial correlation. Table 4 shows the result of these tests, exposing heteroskedasticity issue in both of the models.

Table 4

Model diagnostics. Significance code: '$***$': 0.001, '$**$': 0.01, '$*$': 0.05, '.': 0.1

Test	Statistics	Inference
Bubble Model		
BP Test	123.55***	Heteroskedasticity
DW Test	1.9683	No serial correlation
Fundamental Model		
BP Test	74.59**	Heteroskedasticity
DW Test	2.0039	No serial correlation

Since heteroskedasticity has been identified, I use Newey and West, 1987 covariance matrix for the later inferences. Table 5 presents the t-test for each estimators. Observe that the Adj. R^2 for the bubble model is much higher than that of the fundamental model. This is generally true, from construction and from interpretation. Recall that from figure 3 it can be observed that the variation of fundamentals is very small compared to the variation of inflation and bubbles. Fundamentals, interpreted as reasonable expectation of output, can only be affected by the output itself. Plenty of economic models tell that technology improvement is the most powerful driven factor of consistent economic growth. The potential improvement of technology may be reflected by the observed output. In fact, in table 5 the long term relationship of fundamental growth and output growth is strongly recognized. On the other hand, inflation is relatively not helpful when explaining fundamental growth.

Something worth-mentioning in table 5 is that inflation and output tend to have negative effect on bubble in the long run. This is consistent with Alqaralleh, 2020, which dependent variable is the return. The negative effect that Alqaralleh, 2020 discovered is largely on the bubbles instead of fundamentals of the stocks. In short run, the interpretation becomes vague, though. In the bubble model it is found that the short run relationship between inflation and the bubbles is positive, but mostly not significant. The significance in the short run relationship between output and the bubbles is even lower, and the effect is mixed. It can be concluded that in short run output barely has effect on stock bubbles.

As for the fundamental model, though the effect of output becomes more important, the low Adj. R^2 shows that the variation of the fundamentals is hardly explained in the model. In long run, only the effect of positive output is recognized. In short run, the effect of current negative output change is specified. The bigger the drop in output, the bigger the drop in fundamental. This might demonstrate the reasonable expectation for risk averse investors, since there is no significance in its positive counterpart.

The result of bound test is shown at table 6. For both of

Table 5

T test of the model. Newey-West standard errors are shown in parentheses. Significance code: '∗∗∗': 0.001, '∗∗': 0.01, '∗': 0.05, '.': 0.1

Variable	Bubble model	Fundamental model	Variable	Bubble model	Fundamental model
Adj. R^2	0.5754	0.1554	β_0	-0.0558** (0.0212)	3.9770e-04* (1.8718e-04)
ρ	-0.8636*** (0.1753)	-9.8423e-02*** (2.6599e-02)	β_1	0.0232 (0.1339)	1.3627e-01. (7.3126e-02)
β_2	-0.0386 (0.1181)	9.5221e-04 (9.5824e-02)	β_3	-0.0233 (0.1084)	1.0193e-02 (7.3694e-02)
β_4	0.0767 (0.0971)	-3.9256e-02 (8.7495e-02)	β_5	0.2023 (0.1224)	1.8053e-01* (7.4901e-02)
φ_1^+	-0.1703* (0.0655)	2.7980e-04 (4.7421e-04)	φ_1^-	-0.1736** (0.0624)	5.8501e-04 (4.5681e-04)
φ_2^+	-0.0052* (0.0024)	1.4008e-04*** (3.8602e-05)	φ_2^-	-0.0048 (0.0031)	-5.6932e-06 (2.0355e-05)
δ_0^+	0.1038. (0.0594)	3.2196e-04 (3.0070e-04)	δ_0^-	0.0523 (0.0594)	3.6631e-05 (2.7289e-04)
δ_1^+	0.2127* (0.0955)	-1.7905e-04 (5.0138e-04)	δ_1^-	0.0960 (0.0733)	-2.1501e-04 (4.3137e-04)
δ_2^+	0.0777 (0.0821)	-3.1584e-04 (5.1079e-04)	δ_2^-	0.3235* (0.1350)	-2.8834e-04 (3.8269e-04)
δ_3^+	0.1982* (0.0856)	1.2641e-03** (4.5464e-04)	δ_3^-	0.2014* (0.0796)	-7.1896e-04 (4.6510e-04)
δ_4^+	0.2758** (0.1028)	1.8773e-04 (3.1143e-04)	δ_4^-	0.1216. (0.0689)	-3.5127e-04 (3.7045e-04)
δ_5^+	0.1588* (0.0684)	-6.3690e-05 (2.6730e-04)	δ_5^-	0.0893. (0.0484)	4.8590e-04 (4.0733e-04)
δ_6^+	0.0898. (0.0505)	-6.7755e-06 (3.6809e-04)	δ_6^-	0.0689 (0.0463)	4.7651e-04 (3.4885e-04)
δ_7^+	0.0599. (0.0594)	-7.6509e-05 (2.8637e-04)	δ_7^-	0.1116. (0.0661)	3.2862e-04 (3.0776e-04)
λ_0^+	-0.0141 (0.0160)	-8.3321e-05 (1.5455e-04)	λ_0^-	-0.0007 (0.0039)	1.7816e-04*** (3.6246e-05)
λ_1^+	-0.0328 (0.0246)	1.8962e-04 (1.6319e-04)	λ_1^-	0.0127 (0.0133)	-4.7281e-05 (3.4989e-05)
λ_2^+	0.0344* (0.0137)	-5.6325e-05 (1.8233e-04)	λ_2^-	0.0127 (0.0098)	-1.1740e-05 (7.1317e-05)
λ_3^+	0.0305 (0.0231)	-3.9460e-04* (1.8720e-04)	λ_3^-	-0.0183 (0.0115)	1.0826e-04. (5.7602e-05)
λ_4^+	0.0033 (0.0155)	-5.0695e-05 (2.1519e-04)	λ_4^-	-0.0052 (0.0089)	1.1424e-04. (6.8059e-05)
λ_5^+	-0.0184 (0.0226)	-1.3249e-04 (1.4303e-04)	λ_5^-	0.0322* (0.0148)	-6.6059e-05 (8.5979e-05)
λ_6^+	0.0056 (0.0142)	-1.2617e-04 (1.7406e-04)	λ_6^-	0.0279 (0.0179)	-5.9203e-05 (9.6086e-05)
λ_7^+	0.0317 (0.0195)	-1.1532e-04 (1.9056e-04)	λ_7^-	-0.0157 (0.0154)	1.3658e-05 (6.8190e-05)

the models, the null hypothesis described in equation 3 is rejected. Also, from table 5 it is known that the estimators of ρ are both negative and significant. Hence, cointegrations are detected in both of the models. However, since the long term coefficients of inflation are not significant in the fundamental model, it is hard to say that the cointegration relationship includes inflation in the fundamental case. In fact, due to low explanatory ability and the lower absolute value of ρ, the strength of the cointegration is relatively weaker.

Table 6

Bound F test for long run cointegration. Significance code: '∗∗∗': 0.001, '∗∗': 0.01, '∗': 0.05, '.': 0.1

Model	F Statistics	Inference
Bubble	7.95***	Possible cointegration
Fundamental	5.01**	Possible cointegration

Table 7

Long run Wald test. Significance code: '∗∗∗': 0.001, '∗∗': 0.01, '∗': 0.05, '.': 0.1

Variables	$\mathcal{X}^2$ Statistics	Inference
Bubble Model		
Inflation	0.1663	Symmetry
Output	0.0099	Symmetry
Fundamental Model		
Inflation	25.292***	Asymmetry
Output	22.769***	Asymmetry

Table 8

Short run Wald test. Significance code: '∗∗∗': 0.001, '∗∗': 0.01, '∗': 0.05, '.': 0.1

Variables	$\mathcal{X}^2$ Statistics	Inference
Bubble Model		
Inflation	1.4386	Symmetry
Output	0.0019	Symmetry
Fundamental Model		
Inflation	1.0249	Symmetry
Output	7.158***	Asymmetry

Long run asymmetric effects are tested with Wald test, and the results are shown in table 7. All of the long run effects in bubble model are found symmetric. On the other hand, both of the effects are asymmetric in the fundamental model. Inflation tends to raise fewer fundamental values of stock than it reduces while dropping, but this effect is very weak (or does not exist) since the estimations of φ_1^+ and φ_1^- are not significantly different from zero. As for output, a more precise conclusion is that the positive change in output may boost the fundamentals, but the negative change have nearly no effect on the fundamentals in long run.

Meanwhile, short run asymmetric effects are also tested with Wald test. The results are shown in table 8. In the bubble model, no asymmetry is found. In the fundamental model, only the asymmetric effect that output has on fundamentals is identified. The significance of λ_0^- illustrates that fundamentals react to drop of output in high speed. This can be demonstrated by a risk averse investor in the market who is afraid of a sudden lost.

Figure 4

Fitted values of the bubble model

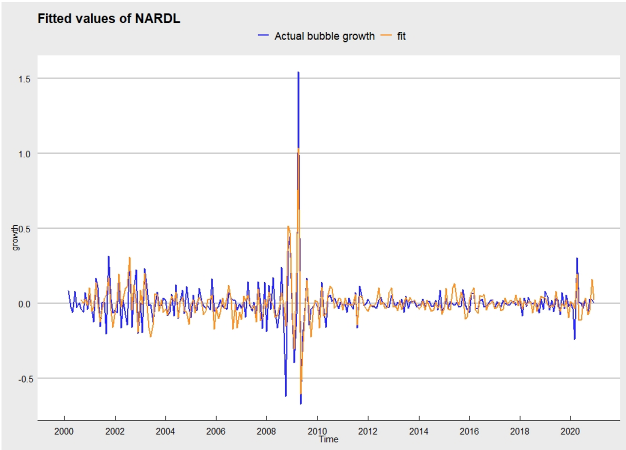
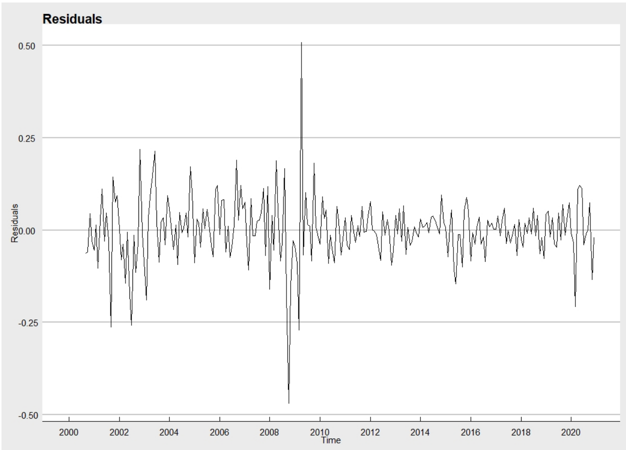


Figure 5

Residuals of the bubble model



Finally, the fitted values and the residuals of the bubble model are demonstrated in figure 4 and 5, and their fundamental counterparts are shown in figure 6 and 7. The explanatory abilities of the models are visualized. It is clearly that the volatility of the fundamentals is difficult to be ex-

Figure 6

Fitted values of the fundamental model

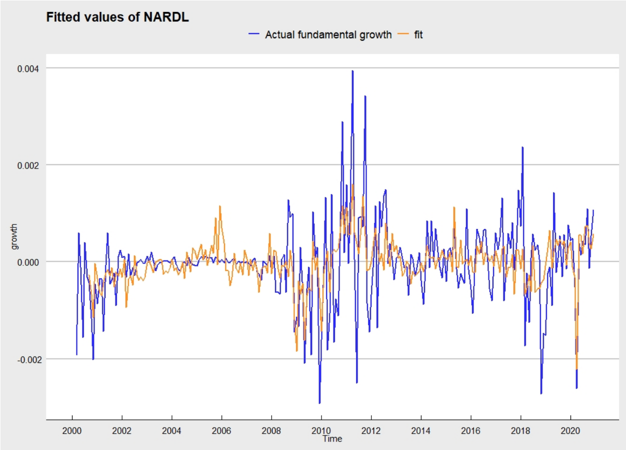
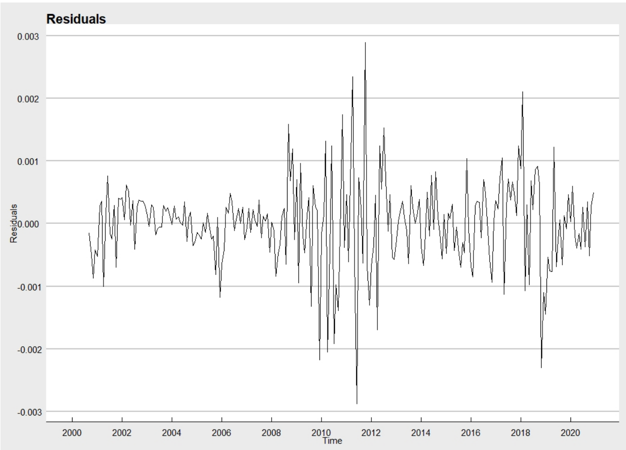


Figure 7

Residuals of the fundamental model



plained only by inflation and output. Nevertheless, the bubble model illustrates the growth of the bubbles well.

Conclusion

I have investigated the cointegration among bubbles, inflation and output, as well as the potential asymmetric effects. The result shows that the bubble react negatively to the increase in inflation rate, and negatively to the positive change of output in the long run. This is so far consistent with Alqaralleh, 2020, which dependent variable is stock return. However, no asymmetric effect is found in the bubble's case. The asymmetric effects appear in the fundamental values of stock, but the model is lack of explanatory ability. The inconsistency with Alqaralleh, 2020 can be the different dependent measures and the different lag selection.

Some interpretation of the result can be made. The negative relation between bubble growth and inflation can be the result of FED's monetary policies. In the investigated period, higher inflation is mostly because of expansionary policy in economic downturn. Stock prices are strongly "adjusted" during such period. Furthermore, decrease in inflation occurs at the beginning of an economic downturn. At that time, bubbles are believed to rise due to the drop in future earnings. Positive increase in output also negatively affects the growth of bubbles. This may be a result of its positive correlation with the growth of fundamentals. These effects become vague in short run, which may be explained by the volatility that the stock market essentially possesses.

As for the fundamental, little evidence of asymmetric effect has been found. The most significant one lies on the short run effect that output has on the fundamental values. The result can be illustrated as the presence of risk averse investors. In conclusion, this article finds that the negative effect that inflation has on stock returns is mostly through its bubble part. However, the asymmetric effect does not appear in bubbles. The effect on fundamental values captures part of the asymmetry, but its explanatory abilities is weak.

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