Short-term Volatility versus Long-term Growth: Evidence in US Macroeconomic Time Series*

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Abstract

We test for a change in the volatility of 215 US macroeconomic time series over the period 1960-1996. We find that about 90% of these series have experienced a break in volatility during this period. This result is robust to controlling for instability in the mean and business cycle nonlinearities. Real variables have seen a reduction in volatility since the early 1980s, which is accompanied by lower but steadier output growth. Furthermore, nominal variables have seen temporary increases in their volatility around the early 1980s. This suggests the existence of a trade-off between short-term volatility and the long-term pattern of growth.

Keywords: volatility, growth, structural change tests, business cycle nonlinearity.

JEL Classification Codes: C52, E32.

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1 Introduction

Fears have been awakened recently that the US economy may be heading for a recession. In January 2001 the Federal Reserve Board of Governors twice lowered its target for the federal funds rate by 50 basis points to 5.5 percent. In a related action, the Board approved two consecutive 50 basis point decreases in the discount rate to 5 percent upon the requests of several Federal Reserve Banks. These interest rate measures followed several warning signs from economic data that a recession may be looming. Specifically,

> "These actions were taken in light of further weakening of sales and production, and in the context of lower consumer confidence, tight conditions in some segments of financial markets, and high energy prices sapping household and business purchasing power. Moreover, inflation pressures remain contained." (Federal Reserve Board Press Release, January 3, 2001)

The increasing risk of a downturn in economic activity also showed in the Conference Board's Composite Index of Leading Indicators, which declined for the third consecutive month in December 2000. During the second half of 2000, the leading index decreased 1.6 percent with only four of the ten components advancing. A 1 percent decline in the leading index, coupled with declines in a majority of the 10 components over a six-month period, historically has provided a reliable recession signal (Conference Board (1997)). Perhaps the most dramatic evidence for the gloomy economic prospects was given by the Conference Board's Confidence Measures. The Business Confidence Index plummeted in the fourth quarter of 2000 to reach its lowest level since the second quarter of 1980. This was followed by a sharp decline of the Consumer Confidence Index in January 2001, reaching its lowest level since December 1996. "Consumers' increasing pessimism about the short-term outlook has sent the Confidence Index into territory normally seen prior to a recession." (Conference Board Press Release, January 30, 2001)

Is this recent reversal of fortune for the US economy really a cause for concern? Only 4 years ago the business press was heralding the "taming", or even the "death", of the business cycle. For a large part, this claim was based upon an apparent reduction of variability of aggregate output. Recent empirical evidence from the business cycle literature has confirmed that the volatility of US GDP indeed has declined over the last two decades, see Kim and Nelson (1999), McConnell and Perez Quiros (2000) and Koop and Potter (2000). This documented fall in volatility will not protect an economy from recession but, as fluctuations in growth become more stable, recessions will become less frequent and less severe.

However, even though aggregate output undoubtedly is an important business cycle indicator[1], a crucial characteristic of the traditional notion of the business cycle is that it relates to many different economic variables. For example, Burns and Mitchell (1946) state that

> "... a cycle consists of expansions occurring at about the same time *in many economic activities*, followed by similarly general recessions,..." (Burns and Mitchell (1946, p. 3), emphasis added)

See Diebold and Rudebusch (1992, 1996) for more extensive discussion of this point. Given this defining characteristic of the business cycle, it appears at least somewhat premature to conclude that the business cycle has been tamed based upon the decline in output variability only. Some evidence that decreased volatility is not unique to aggregate output has been obtained, but it is by no means conclusive. McConnell, Mosser and Perez Quiros (1999) report a decline in volatility of all major components of GDP (consumer spending, investment, government purchases and international trade), although some components are found to be more important than others in contributing to the increased stability of aggregate output. Warnock and Warnock (2000) find that the variability of aggregate employment also declined in the early 1980s. Looking at employment in the major sectors of the economy, however, it is found that only employment in (durable goods) manufacturing has become more stable. In particular, the volatility of employment in services-producing sectors has not shown any signs of decline. In some sectors even a trend towards increased variability is apparent. Chauvet and Potter (2001) show that the reduction in volatility

[1] The importance commonly assigned to aggregate output is evidenced by, for example, the often used rule-of-thumb of two consecutive quarterly declines in GDP to date downturns.

of US GDP is shared not only by aggregate employment, but also by aggregate consumption and income. Finally, Watson (1999) documents a decrease in the variability of short-term interest rates since 1985, but an increase in the variability of long-term interest rates occurring at the same time.[2]

In this paper, we further investigate the extent of the change in the variability of economic fluctuations by testing for a change in the volatility of a wide range of US macroeconomic variables. We utilise the data set compiled by Stock and Watson (1999), which consists of 215 monthly time series observed over the period 1959-1996. We show that about 90% of these series have experienced a break in volatility during this period. Real variables have generally seen a reduction in volatility since the early 1980s, which is accompanied by lower but steady output growth. Furthermore, nominal variables (money, credit, interest rates and producer and consumer prices in particular) have witnessed temporary increases in volatility during the 1970s or early 1980s. Our results are robust to controlling for instability in the mean and for business cycle nonlinearity in both mean and variance. Based upon this evidence, we conclude that the increased stability of economic fluctuations is a wide-spread phenomenon and, hence, that it appears that indeed the business cycle has been "tamed". The coexistence of lower volatility in real variables and lower long-term growth accords with the theoretical literature. Recent studies by de Hek (1999), Jones, Manuelli and Stacchetti (1999) and Blackburn and Pelloni (2000) suggest that the stabilisation of external real shocks can actually reduce long-term growth.

The plan of the paper is as follows. In Section 2 we detail the data set used in our analysis and illustrate the changing nature of growth and volatility by examining the components of the Conference Board's Composite Index of Coincident Indicators. Section 3 describes the tests for structural change in volatility. Section 4 contains the discussion of the empirical results. Section 5 reconciles our results with different explanations that have been put forward for the reduced variability of economic fluctuations. Finally, Section 6 contains our summary and conclusions.

[2]These contradictory findings are reconciled by an increase in the persistence of short-term rates.

2 Data

We examine the data set compiled by Stock and Watson (1999), consisting of 215 monthly US macroeconomic time series. The series are grouped in the following categories, with the number of series in each category in parentheses: production (including personal income) (24), (un)employment (29), wages (hours and earnings) (7), construction (including housing starts) (21), trade (wholesale and retail) (10), inventories (10), orders (14), consumption (5), money and credit (21), stock prices (11), stock market dividends, price-earnings and volume (3), interest rates (11), exchange rates (6), producer prices (16), consumer prices (16), and miscellaneous (e.g. consumer confidence, imports and exports, and National Association of Purchasing Management (NAPM) diffusion indexes) (11). The sample period starts in January 1959, although some series are not available from the beginning[3] and ends in December 1996 (456 observations). The series in dollars, real quantities and price deflators are transformed to logarithms. A detailed description of the data set is given in the appendix of Stock and Watson (1999).

To provide a preliminary indication of the types of structural change that have occurred during the sample period, we observe the four components of the Conference Board's Composite Index of Coincident Indicators - the index of industrial production, employees on nonagricultural payrolls, personal income less transfer payments, and manufacturing and trade sales. Table 1 displays the mean and standard deviation of monthly growth rates of these four series in National Bureau of Economic Research (NBER) dated business cycle phases over the period January 1960-December 1996, while Figure 1 contains the corresponding graphs.

- insert Table 1 and Figure 1 about here -

Output growth was unusually low and extremely volatile during the recessions following the first and second OPEC oil crises. Mean growth returned to "normal" levels in the last two recessions of the century, while volatility dropped below 1970 levels during the 1990-1991 recession. More pronounced is the considerable decline

[3] In addition, to avoid the essentially flat exchange rates during the Bretton Woods period, the first observation used for exchange rates is January 1973.

of both the mean and volatility of growth in expansions since the early 1980s. These features are also evident from the graph of the monthly output growth rate shown in panel (a) of Figure 1. By and large, similar changes are observed for aggregate employment, where the substantial reduction in volatility in the last two recessions is especially noteworthy. The same cannot be said for personal income and manufacturing trade and sales though. For personal income, the only obvious change that has taken place is a decline in the mean growth rate in expansions. For sales it is even more difficult to recognize any consistent patterns in growth and variability based on the figures in Table 1, although volatility appears to have been lower in the most recent expansion than before.

3 Testing for Structural Change in Volatility

Our analysis is based upon univariate tests for discrete changes in volatility. Specifically, we consider an autoregressive (AR) model with a single structural change in the variance at time τ

$$y_t = \phi_0 + \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + \varepsilon_t, \qquad t = 1, \ldots, T, \tag{1}$$

where $\varepsilon_t | \Omega_{t-1} \sim N(0, \sigma_t^2)$ with

$$\sigma_t^2 = \sigma_1^2 \mathtt{I}(t \leq \tau) + \sigma_2^2 \mathtt{I}(t > \tau), \tag{2}$$

with $\mathtt{I}(A)$ denoting the indicator function for the event A, that is $\mathtt{I}(A) = 1$ if A is true and $\mathtt{I}(A) = 0$ otherwise, and Ω_{t-1} is the information set at time t consisting of lagged values of y_t and ε_t.

Let $F_T(\tau)$ denote a Likelihood Ratio (LR), Lagrange Multiplier (LM) or Wald (W) statistic of the hypothesis of constant variance, $\mathsf{H}_0 : \sigma_1^2 = \sigma_2^2$, for fixed break date τ. We treat the break date as unknown and use the procedures developed by Andrews (1993) and Andrews and Ploberger (1994), which correspond to certain functionals of the pointwise statistics $F_T(\tau)$ for $\tau = \tau_1, \ldots, \tau_2$. Specifically, we consider the supremum, average and exponential statistics, given by

$$\mathrm{SupF} = \sup_{\tau_1 \le \tau \le \tau_2} F_T(\tau), \tag{3}$$

$$\mathrm{AveF} = \frac{1}{\tau_2 - \tau_1 + 1} \sum_{\tau=\tau_1}^{\tau_2} F_T(\tau), \tag{4}$$

$$\mathrm{ExpF} = \ln \left(\frac{1}{\tau_2 - \tau_1 + 1} \sum_{\tau=\tau_1}^{\tau_2} \exp\left(\frac{1}{2} F_T(\tau) \right) \right), \tag{5}$$

where F=LR, LM or W.

We compute the tests imposing 15 % symmetric trimming, that is we set $\tau_1 = [\pi T]$ and $\tau_2 = [(1-\pi)T] + 1$ with $\pi = 0.15$, where $[\cdot]$ denotes integer part.[4] The alternative model for fixed τ, as given in (1) with (2), is estimated by maximum likelihood. The value of τ that maximizes $F_T(\tau)$ in (3) is taken to be the estimate of the break date. Andrews (1993) and Andrews and Ploberger (1994) derive the non-standard asymptotic distributions of the supremum, average and exponential statistics. Throughout the paper we use the method of Hansen (1997) to obtain approximate asymptotic p-values.[5]

We consider AR models for first differences of the series.[6] The order of the AR model is determined by the Akaike Information Criterion (AIC), with the maximum order set equal to $p_{\max} = 12$. As remaining residual autocorrelation may be mistaken for structural change, we apply the Breusch-Godfrey LM test to examine the significance of the first 12 residual autocorrelations in the AR(p) model that is selected by the AIC. If necessary, the lag length p is increased until the null hypothesis of no residual autocorrelation can no longer be rejected at the 5% significance level. The final AR order differs from the order selected by AIC for 37 series.[7]

[4]Repeating the computations with different trimming percentages ($\pi = 0.10$ and 0.20), we found that the results are fairly insensitive to the choice of π.

[5]This method renders p-values which are valid only asymptotically. However, given our sample size of $T = 456$, we conjecture that a bootstrap procedure as discussed in Diebold and Chen (1996) would render very similar conclusions.

[6]Qualitatively similar results are obtained with AR models for levels (including a linear time trend as additional regressor).

[7]To examine the sensitivity of our results to this method of order determination, we re-computed all tests with AR orders a) selected with the Schwarz information criterion (BIC) in combination with the Breusch-Godfrey test, b) selected with the AIC, BIC or the Breusch-Godfrey test individually, and c) fixed at $p = 6$ or 12. Finally, we also considered longer maximum lag lengths

4 Empirical Results

We uncover similar results to previous work that real variables have seen a reduction in variability since the 1980s. A more surprising result is that many nominal series appear to actually have experienced an increase in volatility. The remainder of this section details the outcomes of our initial break tests. Sections 4.1 and 4.2 report results controlling for a structural change in mean and for business cycle nonlinearity, respectively. The final section examines the possibility that the increase in volatility found for many nominal variables has been only a temporary phenomenon.

Table 2 contains fractions of rejections of constant variance based upon the likelihood ratio statistics, and the median percent change in the standard deviation for the series for which the null is rejected at the indicated significance levels.[8] Results for the LM and Wald statistics are very similar throughout and are available upon request.

- insert Table 2 about here -

At the 5% significance level, a change in volatility is detected for approximately 90% of the series. Figure 2 shows a histogram of the percent change in standard deviation for the 200 series for which the SupLR statistic is significant at the 5% level.[9] For 135 series, the change is negative, indicating that in general volatility has declined. The median change in the standard deviation is close to minus one-third. For the AveLR and ExpLR statistics these numbers are very similar (negative changes for 131 and 135 series, respectively). Figure 3 shows a histogram of the break dates obtained from the SupLR statistic, again for the series for which the statistic is significant at the 5% level. It is seen that the instability occurs fairly

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($p_{\max} = 18$ and 24). In all cases, the results are qualitatively similar to the ones reported in the paper, and are available upon request.

[8]We report the median percent change instead of the mean because there are a few series for which the standard deviation increases more than ten-fold, and the resulting percent changes distort the mean change completely. The series with the five largest increases in volatility are the crude petroleum price index (dated in February 1969), the net change in commercial and industrial loans (December 1969), the secondary market yield on fha mortgages (November 1965), Moody's Aaa corporate bond yield (February 1966), and the net change in consumer installment credit (December 1980).

[9]Series for which the standard deviation more than doubles are collected in the right-most category.

uniform across the sample period, although there is some concentration of break dates around 1983-1984 and 1991.

- insert Figures 2 and 3 about here -

An interesting difference occurs between real variables (production, employment, wages and salaries, construction, trade, inventories, orders, consumption and miscellaneous) and nominal variables (money and credit, stock prices, interest rates, exchange rates, producer prices, and consumer prices). Of the 120 (out of 131) real variables for which instability in variability is detected, the change in volatility is negative (positive) for 98 (22) series. By contrast, of the 80 (out of 84) nominal variables for which instability in variability is detected, the change in volatility is negative (positive) for only 37 (43) series.

Figure 4 shows scatters of the estimated break date from the SupLR test against the percent change in standard deviation for series for which the statistic is significant at 5% level for real and nominal variables separately. From these graphs, it appears that there exists a strong negative relationship between the timing and the magnitude of the change in volatility. For real and nominal variables, the correlation between the break date and percent change in standard deviation equal -0.49 and -0.65, respectively. In fact, all but four of the decreases (increases) in the volatility of nominal series are dated after (before) 1980.

- insert Figure 4 about here -

Table 3 contains detailed results per group of series. For most groups, a change in volatility is detected for all series but one or two, except for orders, where no change is found for 5 of the 14 series. The median change in standard deviation is negative, and for most groups it is of similar magnitude as the overall median. The largest reductions in volatility have occurred for consumer prices, stock prices and (un)employment series. Money, interest rates and exchange rates exhibit increased volatility on average.

- insert Table 3 about here -

Figure 5 contains group-wise scatters of the estimated break date from the SupLR test against the percent change in standard deviation for series for which the statistic is significant at 5% level. It is difficult to distinguish consistent patterns in the timing of the changes in variability, as there is much within-group heterogeneity, although some features are noteworthy. For 10 of the 24 production series the variance change is dated in 1984, corresponding with the findings of McConnell and Perez Quiros (2000) who date a break in the volatility in US GDP in the first quarter of 1984. Both personal income series included in this group actually experience increases in volatility after the break. The instability in the (un)employment series (and wages) is concentrated around 1980-1985.[10] In sharp contrast to Warnock and Warnock (2000), we find convincing evidence that the variability of employment has decreased in all sectors of the economy, including services. For example, the SupLR test indicates that the standard deviation of employment in the broader services-producing sector has declined by 44% in September 1983. Reductions in variability of employment in other sectors are of similar magnitude and also dated in the first half of the 1980s.[11] The volatility of several of the construction series increased due to housing booms, especially commercial properties in 1968 and houses sold in the North East from the late 1970s. In the inventories data the business durables inventories actually experienced a decrease in volatility at about 1970 whereas McConnell and Perez Quiros (2000) date the break in the quarterly series at the beginning of 1984. The inventory to sales ratios generally have seen increases in volatility, apart from the manufacturing sector.

- insert Figure 5 about here -

As noted above, nominal variables generally experienced increases in volatility. Both producer prices and consumer prices of inputs experienced substantial increases in volatility in the 1970s, due to higher commodity prices after the first oil price

[10] To obtain a more precise estimate of the date of change in volatility of unemployment it might be worthwhile to test for and date a common break in (a subset of) the unemployment series, by suitably adapting the techniques in Bai, Lumsdaine and Stock (1998). We do not pursue this here however.

[11] Warnock and Warnock (2000) do not formally test for changes in volatility, but base their conclusions on observed volatility patterns from stochastic variance models.

shock. In the money group the variability of broad money measures (M2, M3 and L) increased early in the sample, around the late 1960s, whereas narrow money's (M1) volatility increased later in 1980. Consumer credit had large increases in volatility in the early 1980s. This period was during the Federal Reserve Bank chairman Paul Volcker's experiment in "practical monetarism" (see Dow, 1998, p. 333) when interest rates were used as the primary instrument for boosting US GDP. Real GDP was flat until 1982 which gave way to a rapid credit expansion. Further monetary policy measures were then used to reign in the credit boom. This meant that the early 1980s was an extremely volatile time for interest rates. Comparing the pre- and post-Volcker periods, we find that for the majority of longer to maturity interest rates volatility has increased, whereas the variability of short-term rates (the Federal Funds rate and the three and six month Treasury Bill rates in particular) has decreased, cf. Watson (1999).[12] For 8 of the 11 stock price series the change is dated in 1991, here the majority of these series experienced large falls in volatility in the last recession of the sample period. The variability of the exchange rate of the US dollar against the German DMark, the Swiss franc and the Japanese yen increased substantially in 1978, while a decline in the variability of the exchange rate against the British pound is found to have occurred in 1993.

4.1 Controlling for a structural change in mean

A legitimate question to ask is whether our findings of structural change in the conditional variance are not due to neglected structural change in the parameters in the AR model for the conditional mean. In fact, Kim and Nelson (1999) argue that a smaller gap between mean growth rates during expansions and contractions is much more important than any decline in the volatility of shocks in explaining the increased stability of US GDP after 1984. As can be seen from Table 1, the difference between mean growth rates during the two business cycle phases appears to have become smaller for all four components of the coincident indicator index as well. Hence, this feature may explain at least part of our results.

[12]The possibility that the increased volatility that is found for many nominal variables was a temporary phenomenon only is investigated in more detail in Section 4.3 below.

We address this issue as follows. First, we compute SupLR, AveLR and ExpLR statistics for a structural change in the AR coefficients in (1), assuming the error variance to be constant,[13] again using 15% trimming and the method of Hansen (1997) to obtain approximate asymptotic p-values. Percent rejections from those tests are shown in Table 4. These correspond remarkably well with results reported in Stock and Watson (1996) based on a similar set of data. Overall, the SupLR test rejects stability for almost half of the series at the 5% level. The second column of Table 5 shows how these rejections are distributed across the different groups, by listing the number of series in each group for which stability of the AR coefficients is rejected. Note that (virtually) no evidence for instability is found for the construction, trade, stock price and exchange rate series. Instability is widespread especially among interest rates and producer and consumer prices.

- insert Tables 4 and 5 about here -

Next, we examine how much of the evidence for a change in volatility is left after we allow for a structural change in the conditional mean. Specifically, we apply the likelihood ratio tests for a structural change in variance while allowing for a structural change in the AR coefficients at the date indicated by the SupLR statistic (for a change in the conditional mean, of course) for all series.[14]

The second line of Table 6 contains percent rejections at the 5% level of these tests and the median percent change in standard deviations. Comparing these with the corresponding figures of the "base-line case", which are given in the first line of Table 6 for completeness, shows that the results hardly change. Instability in the variance is still detected for approximately 90% of the series while the median percent change is still less than -30%. The dating of the change in variance also is not affected by neglecting a possible structural break in mean. For 142 series, the

[13]This assumption allows us to use the asymptotic distributions of Andrews (1993) and Andrews and Ploberger (1994). As shown by Hansen (2000), the asymptotic distributions of the supremum, average, and exponential test statistics for a change in mean are affected by a structural change in variance (although the asymptotic size distortions are not extremely large, in particular for the exponential test). Using Hansen's (2000) "fixed regressor" bootstrap to produce the correct asymptotic distribution, we obtain virtually identical results to the ones reported here.

[14]Results do not change if we allow for a structural change in the mean only in the series for which the SupLR statistic is significant.

variance change conditional on a change in mean is dated in exactly the same month as the variance change in the base-line case. The two break dates are more than a year apart for 31 series only. Furthermore, the variance change in the base-line case is not spuriously located at the time of the change in mean. This can be seen from Figure 6, which shows a scatter of the break dates from the SupLR test for a structural change in mean against the break dates from the SupLR test for a change in the variance in the base-line case for all 215 series. It appears that there is hardly any relationship between the two break dates. In fact, the correlation between the corresponding observation numbers is equal to -0.034. To summarize, even though a structural change in the mean might be present in many macroeconomic time series, it cannot account for our findings of a structural change in volatility.

- insert Table 6 and Figure 6 about here -

4.2 Controlling for business cycle nonlinearity

A second type of misspecification of the model under the null hypothesis that may be influencing our results is neglected nonlinearity, either in the conditional mean or in the conditional variance. Specifically, many US macro-economic time series exhibit asymmetry over the business cycle, see Sichel (1993), Ramsey and Rothman (1996), Acemoglu and Scott (1997) and Verbrugge (1997), among many others. Lundbergh, Teräsvirta and van Dijk (2000) apply linearity tests to the same data set we use here and find considerable evidence for business cycle asymmetry. This implies that possibly different AR models should be used during recessions and expansions.

We formally test for business cycle nonlinearity in the conditional mean by computing likelihood ratio statistics for equality of the AR coefficients during recessions and expansions, where we use the NBER chronology to date the business cycle phases.[15] As shown in the second column of Table 7, for 65% of the series we reject linearity at the 5% significance level. The third column of Table 5 shows how these rejections are distributed across the different groups, by listing the number of series

[15] Note that in this case the likelihood ratio statistic has a conventional asymptotic chi-square distribution.

in each group for which linearity is rejected. Nonlinearity appears to be very common among production, (un)employment, trade, inventories, orders, interest rates and consumption series. Also note that no evidence for nonlinearity is found for stock prices and exchange rates.

- insert Table 7 about here -

Next, we examine how much of the evidence for a change in volatility is left after we allow for nonlinearity in the conditional mean. Specifically, we apply the likelihood ratio tests for a structural change in variance while allowing for a different AR model during NBER-dated recessions and expansions for all series.[16] The third line of Table 6 contains percent rejections at the 5% level of these tests and the median percent change in standard deviations in this case. Comparing these with the corresponding figures of the base-line case shows that again the results change only marginally. Instability in the variance is still detected for approximately 90% of the series while the median percent change is still less than -30%. Hence, even though business cycle asymmetry appears to be an important feature of many macroeconomic time series, it cannot account for our findings of a structural change in volatility.

As a final robustness check, we examine whether our results may be due to neglected nonlinearity in the variance. The volatility of macro-economic time series tends to be larger during recessions than during expansions, see Brunner (1992), French and Sichel (1993), and Warnock and Warnock (2000), among others. Given that after the trough of November 1982 only eight months (August 1990-March 1991) are coined as "recession", it may be that the apparent structural change in volatility may simply be due to the "lack of recessions" during the latter part of our sample period.

We first formally test for different variances during recessions and expansions in a linear AR model, again using the NBER dated peaks and troughs to define these business cycle phases. The third column of Table 7 shows that for 67% of the series

[16]Results do not change if we allow for nonlinearity in the mean only for the series for which the LR statistic is significant.

we reject "linearity" of volatility at the 5% significance level. The median difference in standard deviations during recessions and expansions equals -32% (expressed as percent of the standard deviation during recessions). The standard deviation during expansions actually is smaller than the standard deviation during recessions for 142 of the 145 series for which linearity is rejected (and in general for 197 of the 215 series). This is also visible from the fourth and fifth columns of Table 5, which show the number of series in each group for which linearity of the variance is rejected and the median percentage difference in standard deviations during recessions and expansions. The difference in standard deviations is largest (in absolute value) for interest rates, production series and stock prices. Also note that for 10 of the 11 stock price series, nonlinearity in the variance is indicated, in contrast to the results for structural change and nonlinearity in the conditional mean for these series.

Next we compute likelihood ratio statistics for a structural change in variance during NBER-dated expansions, while allowing volatility to be different during expansions and recessions for all series.[17] Testing for a change in volatility during expansions only seems appropriate given our conjecture that the evidence for a structural change in variance might be due to a lack of recessions during the last 14 years of the sample. The fourth line of Table 6 contains percent rejections at the 5% level of these tests and the median percent change in standard deviations (during expansions) in this case. Comparing these with the corresponding figures of the base-line case shows that again the results change only marginally. Instability in the variance during expansions is still detected for almost 90% of the series while the median percent change is still equal to -30%. Hence, neglected nonlinearity in the variance cannot account for our findings of a structural change in volatility. Put differently, our results are not driven by a lack of recessions during the last 15 years of the sample period.

The final two columns of Table 5 show the number of series in each group for which stability of the variance during expansions is rejected and the median percentage change in the standard deviations during expansions. As in the base-

[17]Again, results do not change if we allow for nonlinearity in the variance only in the series for which the LR statistic is significant.

line case, the largest reductions in volatility have occurred for consumer prices and (un)employment series, whereas volatility has increased for money and credit, interest rates and exchange rates.

Figure 7 shows a scatter of the percent difference in standard deviations during recessions and expansions and the percent change in the standard deviation during expansions, when the break date indicated by the SupLR is used, for all 215 series. It appears that there is hardly any relationship between these percentages. In fact, the correlation is equal to 0.047.

- insert Figure 7 about here -

Finally, we combine the three robustness checks discussed above, that is we test for a structural change in volatility during NBER-dated expansions while allowing for nonlinearity in the conditional mean and in the conditional variance and allowing for a structural change in the AR model for the conditional mean during expansions. The date of the latter change is determined by applying the SupLR test in a model which allows for nonlinearity in the conditional mean but assumes constant variance. Results from applying likelihood ratio tests for structural change in volatility in this case are summarized in the last line of Table 6. Again, the percent rejections and median percent change in the standard deviation are very similar to previous figures.

4.3 Multiple changes in volatility

For many nominal variables short periods of extreme volatility appear to have occurred, such as the mid-1970s for inflation rates and the early 1980s for interest rates. In the presence of such temporary outbursts of volatility, results based on tests for a single change in volatility can be quite misleading. Intuitively, the single break will be dated either at the beginning or at the end of the extremely volatile period (depending on the relative magnitude of volatility before and after this subperiod and the position of the period of extreme volatility in the full sample), and it will appear that variability has experienced a substantial increase and decrease, respectively. In case the period of extreme (but temporary) volatility coincides for different series, this will also lead to a negative relationship between the timing and the magnitude of the change in volatility, such as shown in Figure 4.

To examine whether the the apparent increase in variability for nominal variables has been only a temporary phenomenon, we test for the presence of multiple changes in volatility using the sequential procedure of Bai (1997), see also Bai and Perron (1998). If the supLR test based on the full sample detects a significant change in variance, the sample is split at the corresponding break point, and the test is then performed on each of the subsamples. If additional significant changes are found, the sample splitting process is repeated until either each resulting subsample contains no significant change or until the subsamples become too small or until the imposed maximum number of five changes is reached. This is followed by a "repartition" procedure, in which the dates of each of the m detected breaks are re-estimated using the full sample and conditional upon the $m-1$ remaining break dates as obtained in the sequential testing procedure. In both the sequential testing and the repartitioning procedures, we require a minimum of 15% of the sample to lie between consecutive breaks.

- insert Table 8 about here -

Table 8 summarizes the results based upon the SupLR test and a 5% significance level for the real and nominal variables separately. We find evidence for two and three changes in variance in 21 and 42 nominal series, respectively. For 46 of these 63 series, the volatility shows a hump-shaped pattern, that is it increases at the first (and second) break followed by a decrease at the second (and/or third) break(s). Comparing the volatility before the first break and after the final break, we find that for 31 (32) series the variability eventually falls (rises). This shows that indeed many nominal variables have experienced a temporary (but large) increase in volatility, although the overall change in volatility is ambiguous.

Table 9 contains detailed results per group of series. It is seen that multiple changes are particularly common among inflation rates and interest rates. The first oil crisis caused a period of extremely volatile inflation rates. For the majority of consumer and producer prices, a significant increase in volatility is found to have occurred in the early 1970s. For most producer prices, this is followed by a decrease in volatility in the late 1970s. The effects on consumer prices appear to have lasted much longer. For these series volatility declined again not earlier than the late 1980s or early 1990s. For interest rates, allowing for multiple changes in volatility effectively "eliminates" the Volcker period, in the sense that changes in volatility are dated just before and immediately after this period. For all but one of the interest rates, we find an additional substantial increase in variance in the second half of the 1960s. Comparing the volatiliy after this first change and after the Volcker period, we confirm the findings of Watson (1999) that the variability of shorter to maturity rates has fallen, whereas the variability of longer to maturity rates has risen.

- insert Table 9 about here -

Finally for the real variables, we find evidence for two and three changes in variance in 43 and 33 series, respectively. For 44 of these 76 series, the volatility shows a hump-shaped pattern, while for 59 series the volatility before the first break is larger than the volatility after the final break. Volatility has decreased for 41 of the 44 series for which only a single in variance seems to be present. This confirms that real variables have experienced a net decline in variability over the sample period.

5 Reconciling Results with Theory

The explanations that have been put forward for the apparent reduction in volatility in macroeconomic variables can roughly be divided into two groups. The first is structural change in the US economy brought about by regulatory shifts or technological innovations, such as the introduction of "just-in-time" inventory management, see McConnell, Mosser and Perez Quiros (1999) and McConnell and Perez Quiros (2000).[18] The second is the co-existence of stabilising monetary policy and smaller economic shocks over the last two decades. In line with the latter explanation, Clarida, Galí and Gertler (2000) provide evidence that over the last twenty years the Federal Reserve's monetary policy has been more aggressive to eliminate inflationary

[18] Interestingly, McConnell, Mosser and Perez Quiros (1999) and McConnell and Perez Quiros (2000) and Warnock and Warnock (2000) convincingly demonstrate that compositional shifts away from notoriously volatile sectors such as manufacturing towards more stable sectors such as services cannot explain the reduced variability of aggregate output, consumption and employment.

pressures before they actually materialise, and as a result has indeed been more stabilising, see also Mussa (1994). Potter (1999) conjectures that the success of the US government's stabilisation policies have reduced the size of negative shocks hitting the economy and possibly also instituted automatic stabilisers that reverse the effect of negative shocks during recession.

As our analysis has been essentially univariate, it is difficult to argue in favor of (or against) either of the two above explanations based upon our results. We do wish to note, however, that our findings are in accordance with the theoretical model of Blackburn and Pelloni (2000). These authors use a stochastic monetary growth model in which learning-by-doing accounts for linkages between short-run (cyclical) and long-run (secular) movements in economic activity. These authors demonstrate that there exists a positive trade-off between real volatility shocks and long-term growth and a negative trade-off between nominal volatility shocks and growth. Our results do show a fall in the volatility of the majority of real macroeconomic series. This is accompanied by a fall in the absolute mean growth rates of industrial production as given in Table 1. Additionally we find increases in volatility of nominal series (albeit temporary ones), which are contributing to the fall in long-term growth.

6 Summary and Conclusions

We have tested for a change in the volatility of the US economy using the data set compiled by Stock and Watson (1999), which consists of 215 monthly US macroeconomic time series over the period 1960-1996. We have shown that about 90% of these series have experienced a break in volatility during this period. This result was found to be robust to controlling for instability in the mean and business cycle nonlinearities. On average, real variables have seen a reduction in volatility since the early 1980s, which is accompanied by lower but steady output growth. Furthermore, many nominal variables have seen (temporary) increases in their volatility. This suggests the existence of a trade-off between short-term volatility changes and the change in the long-term pattern of growth, consistent with the theoretical model presented in Blackburn and Pelloni (2000).

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Table 1: Mean and volatility of coincident indicators

Period	Production		Employment		Income		Sales	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Contractions								
May 1960-Feb 1961	−0.64	0.71	−0.23	0.16	−0.02	0.44	−0.49	1.06
Jan 1970-Nov 1970	−0.55	0.74	−0.11	0.26	−0.05	0.29	−0.38	0.84
Dec 1973-Mar 1975	−1.00	1.43	−0.11	0.33	−0.44	0.53	−0.86	0.99
Feb 1980-Jul 1980	−1.06	1.05	−0.19	0.28	−0.48	0.36	−0.95	1.32
Aug 1981-Nov 1982	−0.62	0.82	−0.19	0.13	−0.11	0.47	−0.38	0.81
Aug 1990-Mar 1991	−0.54	0.51	−0.16	0.05	−0.38	0.53	−0.55	1.04
Expansions								
Mar 1961-Dec 1969	0.53	0.70	0.27	0.19	0.41	0.28	0.45	0.99
Dec 1970-Nov 1973	0.65	0.69	0.28	0.17	0.44	0.54	0.73	1.07
Apr 1975-Jan 1980	0.50	0.72	0.30	0.19	0.35	0.33	0.43	1.13
Aug 1980-Jul 1981	0.60	0.74	0.16	0.12	0.38	0.50	0.31	0.97
Dec 1982-Jul 1990	0.31	0.64	0.23	0.13[1]	0.29	0.41	0.34	1.06
Apr 1991-Dec 1996	0.31	0.42	0.16	0.13	0.21	0.40[2]	0.35	0.77

Mean and standard deviation (SD) of monthly growth rates in the components of the Conference Board's composite index of coincident indicators - the index of industrial production ("Production"), employees on nonagricultural payrolls ("Employment"), personal income less transfer payments ("Income") and manufacturing and trade sales ("Sales") - during contractions and expansions. Business cycle dates taken from NBER (`http://www.nber.org/cycles.html`).

[1] After replacing an outlier in August 1983 by the average of the two neighboring observations.

[2] After replacing an outlier in August 1992 by the average of the two neighboring observations.

Table 2: Tests for structural change in variance - percent rejections and median percentage change in standard deviation over all series

	SupLR		AveLR		ExpLR	
Test size	Reject	% Change	Reject	% Change	Reject	% Change
10% level	94.4	−31.5	92.1	−31.8	94.0	−31.6
5% level	93.0	−31.8	87.0	−32.4	92.6	−31.8
1% level	87.4	−32.9	73.0	−33.9	85.6	−33.1

Columns headed "Reject" contain the percent rejections across all series at the indicated nominal significance levels, where the procedure of Hansen (1997) is used to obtain approximate asymptotic p-values. Columns headed "% Change" contain the median percent change in the standard deviation for those series for which the corresponding test statistic is significant at the indicated significance level.

Table 3: Tests for structural change in variance - number of rejections and median percentage change in standard deviation for groups of series

	SupLR		AveLR		ExpLR	
Group	Reject	% Change	Reject	% Change	Reject	% Change
Production (24)	24	−37.2	22	−40.5	24	−37.2
(Un)Employment (29)	29	−40.7	28	−41.6	29	−40.7
Wages and salaries (7)	7	−39.4	7	−39.4	7	−39.4
Construction (21)	18	−28.3	16	−29.1	18	−28.3
Trade (10)	9	−35.9	8	−36.1	9	−35.9
Inventories (10)	8	−27.3	8	−27.3	8	−27.3
Orders (14)	9	−21.1	9	−21.1	9	−21.1
Consumption (5)	5	−33.1	5	−33.1	5	−33.1
Money and credit (21)	19	71.8	17	73.6	18	72.7
Stock prices (11)	11	−41.6	9	−43.0	11	−41.6
Dividends and volume (3)	2	−12.1	2	−12.1	2	−12.1
Interest rates (11)	11	171.8	11	171.8	11	171.8
Exchange rates (6)	5	77.8	2	38.1	5	77.8
Producer prices (16)	16	−35.6	16	−35.6	16	−35.6
Consumer prices (16)	16	−45.5	16	−45.5	16	−45.5
Miscellaneous (11)	11	−33.2	11	−33.2	11	−33.2
Total (215)	200	−31.8	187	−32.4	199	−31.8

Columns headed "Reject" contain the number of series for which the different tests are significant at the 5% level. Columns headed "% Change" contain the median percent change in the standard deviation across these series.

Table 4: Tests for structural change in mean - percent rejections over all series

Test size	SupLR	AveLR	ExpLR
10% level	57.7	42.3	54.4
5% level	47.9	31.2	47.0
1% level	36.3	17.2	33.5

The table contains percent rejections across all series at the indicated nominal significance levels, where the procedure of Hansen (1997) is used to obtain approximate asymptotic p-values.

Table 5: Tests for business cycle nonlinearity and structural change in mean and variance - number of rejections and median percentage difference/change in standard deviation for groups of series

	Mean		Variance			
	Structural	Non-	Nonlinearity		Structural Change	
Group	Change	linearity	Reject	% Diff	Reject	% Change
Production (24)	13	21	18	−45.0	19	−34.8
(Un)Employment (29)	16	28	23	−34.1	28	−40.0
Wages and salaries (7)	3	0	4	−26.5	7	−36.4
Construction (21)	1	13	18	−20.1	15	−27.0
Trade (10)	2	9	7	−32.0	9	−38.3
Inventories (10)	6	8	9	−23.4	6	−28.2
Orders (14)	9	12	8	−31.0	9	−20.0
Consumption (5)	3	5	3	−29.5	5	−35.6
Money and credit (21)	8	8	9	−26.2	18	79.7
Stock prices (11)	0	0	10	−39.6	10	−35.2
Dividends and volume (3)	2	0	2	−34.6	2	−14.7
Interest rates (11)	10	11	11	−47.5	11	190.8
Exchange rates (6)	0	0	0	–	5	72.6
Producer prices (16)	10	11	12	−26.5	16	−29.6
Consumer prices (16)	16	6	9	−29.1	16	−45.7
Miscellaneous (11)	4	8	2	−37.0	11	−33.6
Total (215)	103	140	145	−32.8	187	−30.3

Columns headed “Mean” contain the number of series for which likelihood ratio tests for structural change and nonlinearity are significant at the 5% level. Columns headed “Variance - Nonlinearity” contain the number of series for which the likelihood ratio test for nonlinearity in variance is significant at the 5% level (“Reject”) and the median percent difference in the standard deviations in recessions and expansions (expressed as percentage of the standard deviation during recessions) for these series (“% Diff”). Columns headed “Variance - Structural Change” contain the number of series for which the SupLR test of structural in the variance during expansions is significant at the 5% level (“Reject”) and the median percent change in the standard deviations during expansions for these series (“% Change”).

Table 6: Tests for structural change in variance - percent rejections and median percentage change in standard deviation over all series

		SupLR		AveLR		ExpLR	
Mean	Variance	Reject	% Change	Reject	% Change	Reject	% Change
Linear	Constant	93.0	−31.8	87.0	−32.4	92.6	−31.8
Change	Constant	92.1	−31.0	85.6	−32.3	89.8	−31.3
Nonlinear	Constant	91.2	−30.3	83.7	−31.2	90.7	−30.3
Linear	Nonlinear	87.0	−30.3	77.7	−32.0	85.6	−30.5
NL/Change	Nonlinear	84.2	−30.3	75.3	−32.1	82.3	−30.5

The table contains results for the SupLR test for a structural change in variance under different assumptions concerning the mean and variance under the null hypothesis. The line "Linear-Constant" contains results from the "base-line" case, with a linear and constant AR model for the conditional mean and a linear and constant variance under the null. The line "Change-Constant" contains results obtained when allowing for a structural change in the conditional mean. The line "Nonlinear-Constant" contains results obtained when allowing for nonlinearity in the conditional mean. The line "Linear-Nonlinear" contains results obtained when imposing nonlinearity in the variance. The line "NL/Change-Nonlinear" contains results obtained when allowing for nonlinearity in both the conditional mean and in the variance and for a structural change in the model for the conditional mean during expansions. In the last two cases, the tests relate to a structural change in the volatility during expansions. Columns headed "Reject" contain the percent rejections across all series at the 5% nominal significance level, where the procedure of Hansen (1997) is used to obtain approximate asymptotic p-values. Columns headed "% Change" contain the median percent change in the standard deviation for those series for which the corresponding test statistic is significant.

Table 7: Tests for business cycle nonlinearity in mean and variance - percent rejections and median percentage difference in standard deviation over all series

	Mean	Variance	
Test size	Reject	Reject	% Diff
10% level	68.8	74.9	−31.5
5% level	65.1	67.4	−32.8
1% level	54.4	60.0	−34.2

Columns headed "Reject" contain the percent rejections across all series at the indicated nominal significance levels. The column headed "% Diff" contains the median percent difference in the standard deviations in recessions and expansions (expressed as percentage of the standard deviation during recessions) for those series for which the test statistic is significant at the indicated significance level.

Table 8: Tests for multiple structural changes in variance - number of rejections and median overall percentage change in standard deviation for groups of series

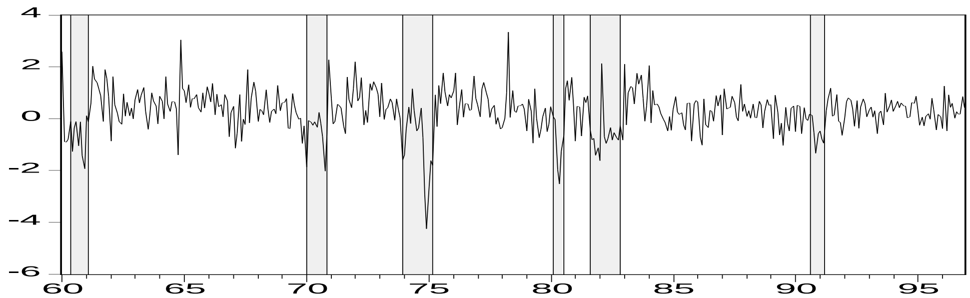
		First Change		Second Change		Third Change		Overall	
m	k	Neg	% Change	Neg	% Change	Neg	% Change	Neg	% Change
				Real Variables (120)					
1	44	41	−33.6	–	–	–	–	41	−33.6
2	43	12	42.9	39	−34.6	–	–	35	−13.8
3	33	9	44.3	21	−33.0	23	−34.0	24	−23.1
				Nominal Variables (85)					
1	17	9	−31.1	–	–	–	–	9	−31.1
2	21	5	48.8	15	−37.8	–	–	14	−10.0
3	42	3	106.1	22	−25.7	35	−45.1	17	12.3

m changes in variability are detected for k series based upon the the supLR test. Columns headed "Neg" and "% Change" under "First Change", "Second Change" and "Third Change" contain the number of series for which the change in standard deviation is negative and the median percent change in the standard deviation at the i-th change ($i = 1, 2, 3$). Columns "Neg" and "% Change" under "Overall" contain the number of series for which the "net" change in standard deviation (that is the difference between the standard deviations after the final change and before the first change) is negative and the median percent "net" change in the standard deviation.

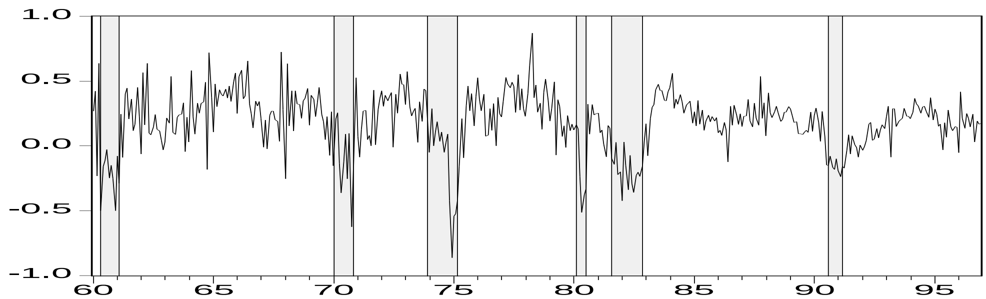
Table 9: Tests for multiple structural changes in variance - number of rejections and median overall percentage change in standard deviation for groups of series

	1 change		2 changes		3 changes		Overall
Group	k	% Change	k	% Change	k	% Change	% Change
Production (24)	13	−40.6	5	−11.5	6	−17.6	−34.5
(Un)Employment (29)	6	−32.6	10	−44.3	13	−40.9	−40.5
Wages and salaries (7)	5	−39.4	1	−47.5	1	−31.5	−39.4
Construction (21)	5	−29.2	7	−11.1	6	−23.1	−17.6
Trade (10)	5	−36.0	4	−18.1	0	–	−34.5
Inventories (10)	2	−30.2	4	−8.8	2	−5.2	−15.4
Orders (14)	3	−26.8	3	38.4	3	−0.5	−6.9
Consumption (5)	2	−31.8	2	16.5	1	−25.2	−30.5
Money and credit (21)	4	38.7	6	79.8	9	60.4	49.5
Stock prices (11)	5	−43.0	5	−17.7	1	−37.3	−35.1
Dividends and volume (3)	1	33.4	1	−72.9	0	–	−19.7
Interest rates (11)	1	−50.7	0	–	10	117.1	100.3
Exchange rates (6)	3	77.8	2	16.9	0	–	68.5
Producer prices (16)	2	−39.1	3	−27.4	11	4.5	−14.4
Consumer prices (16)	1	95.7	4	−16.9	11	−39.0	−26.4
Miscellaneous (11)	3	−37.5	7	−15.5	1	−5.3	−31.9
Total (215)	61	−33.2	64	−13.3	75	−6.5	−22.5

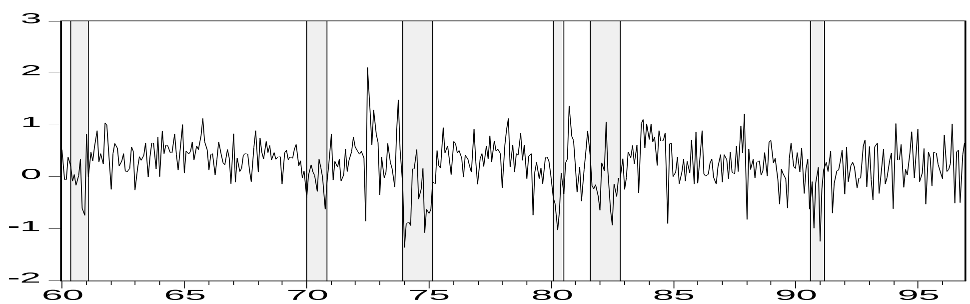
Columns headed "k" contain the number of series for which m changes in variability are found based upon the the supLR test. Columns headed "% Change" contain the median percent "net" change in the standard deviation across these series, that is the difference between the standard deviations after the final change and before the first change. The column headed "Overall - % Change" contain the median percent "net" change in the standard deviation across all series in a group for which at least one change is found.



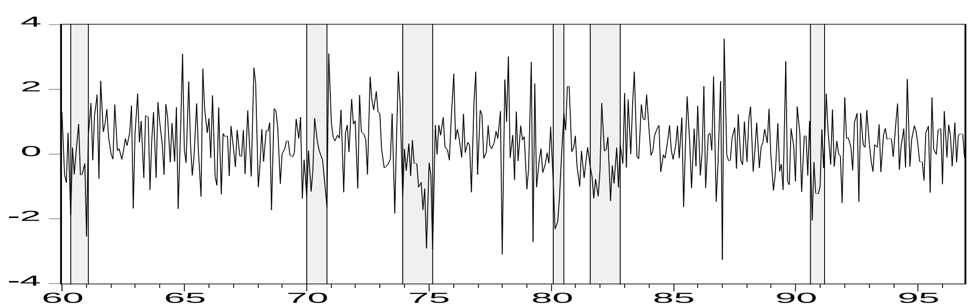
(a) Industrial Production



(b) Employees on nonagricultural payrolls



(c) Personal income less transfer payments



(d) Manufacturing and trade sales

Figure 1: Monthly growth rates of components of the Conference Board's composite index of coincident indicators, January 1960-December 1996. Shaded areas correspond with NBER-dated recessions.

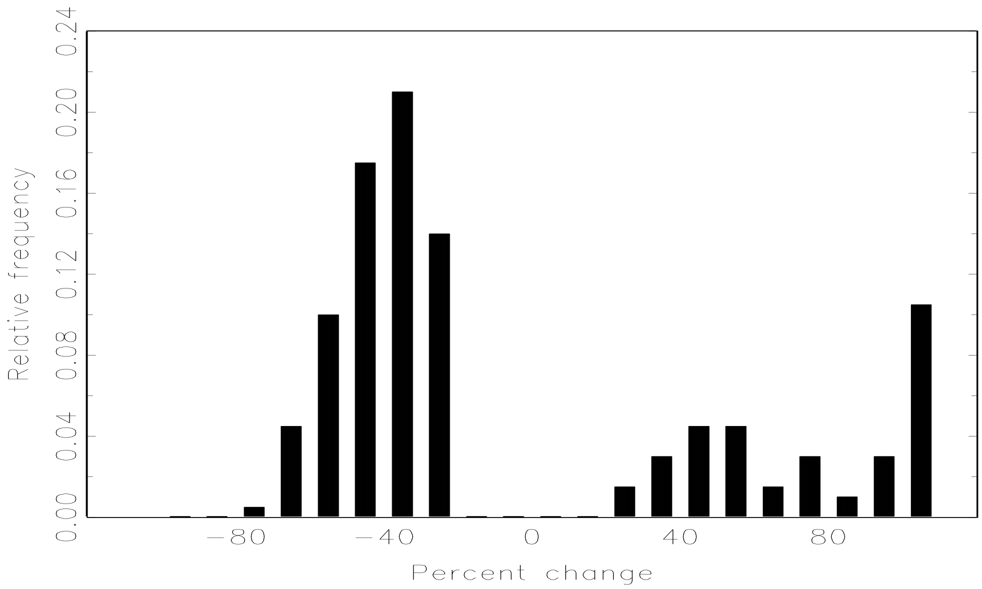


Figure 2: Histogram of percent change in standard deviation for series for which the SupLR statistic is significant at 5% level (200).

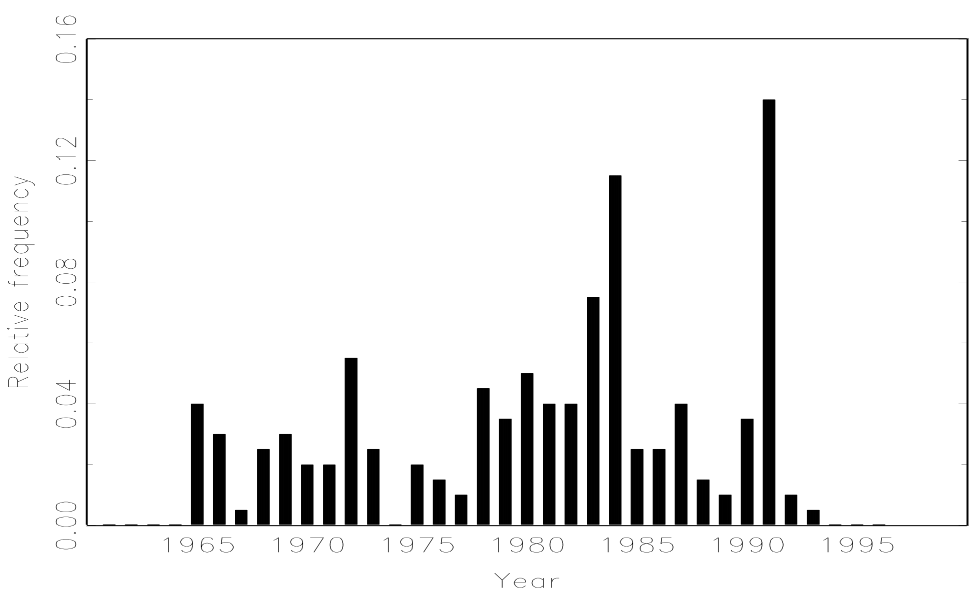
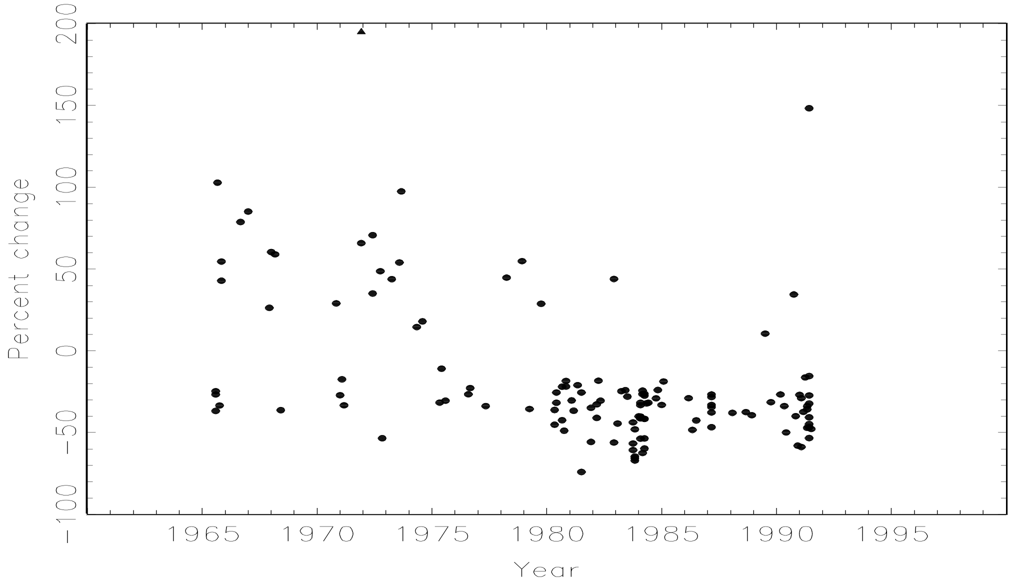
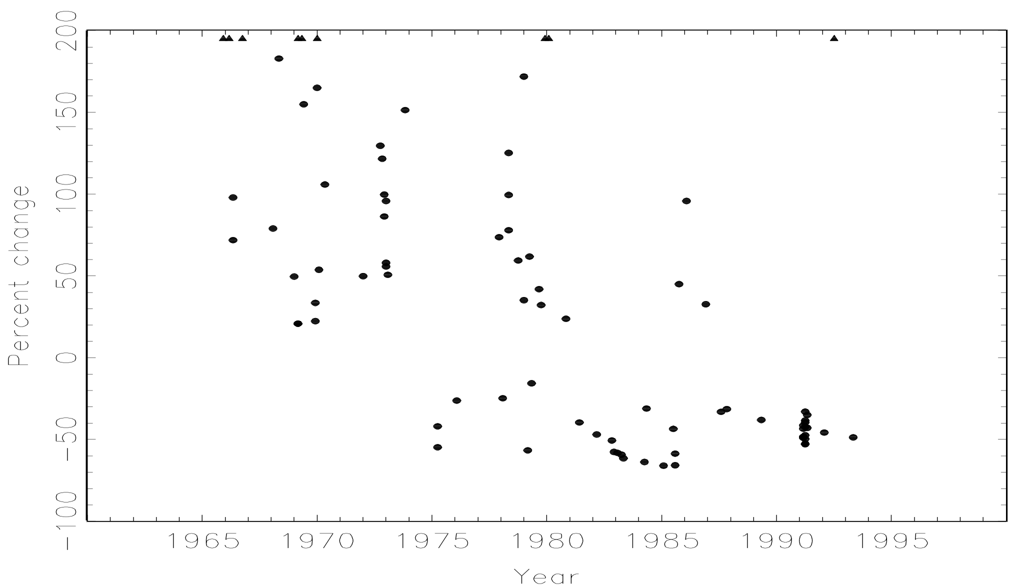


Figure 3: Histogram of break dates from the SupLR test for a change in variance for series for which the statistic is significant at 5% level (200).

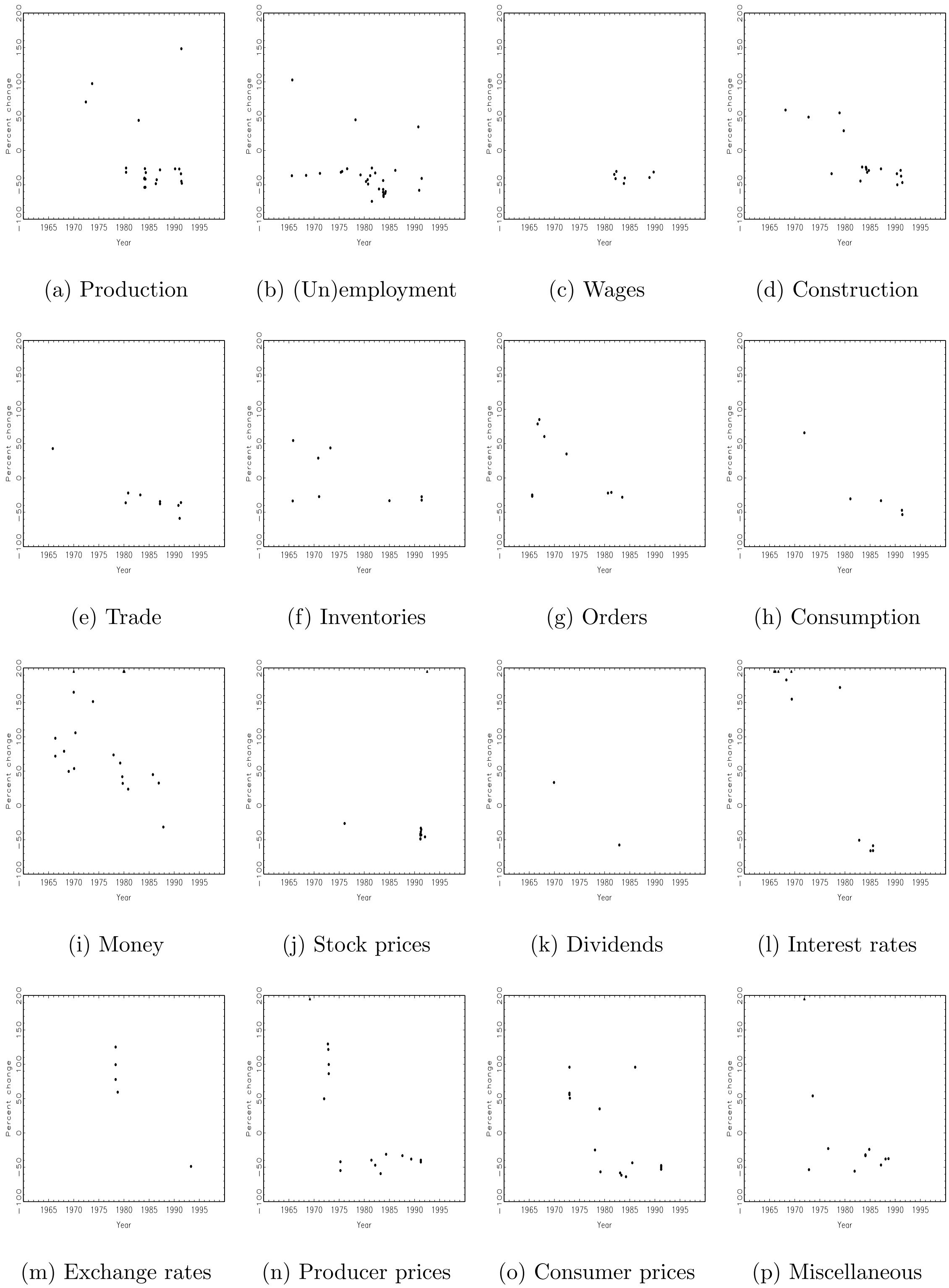


(a) Real series



(b) Nominal series

Figure 4: Scatter of break dates obtained from the SupLR test for a change in variance against percent change in standard deviation for series for which the statistic is significant at the 5% level for real variables (production, (un)employment, wages and salaries, construction, trade, inventories, orders, consumption and miscellaneous) and nominal variables (money and credit, interest rates, producer prices, and consumer prices). Series for which the standard deviation more than triples are shown as triangles.



(a) Production (b) (Un)employment (c) Wages (d) Construction

(e) Trade (f) Inventories (g) Orders (h) Consumption

(i) Money (j) Stock prices (k) Dividends (l) Interest rates

(m) Exchange rates (n) Producer prices (o) Consumer prices (p) Miscellaneous

Figure 5: Scatter of break dates obtained from the SupLR test for a change in variance against percent change in standard deviation for series for which the statistic is significant at the 5% level per group. Series for which the standard deviation more than triples are shown as triangles.

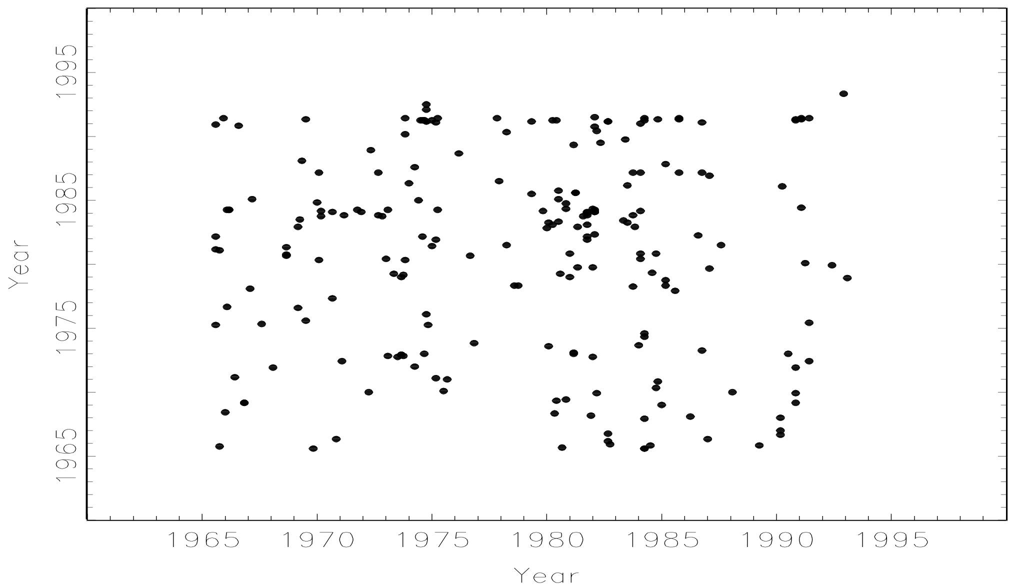


Figure 6: Scatter of break dates obtained from the SupLR test for a change in mean (horizontal axis) against break dates obtained from the SupLR test for a change in variance (vertical axis) for all 215 series.

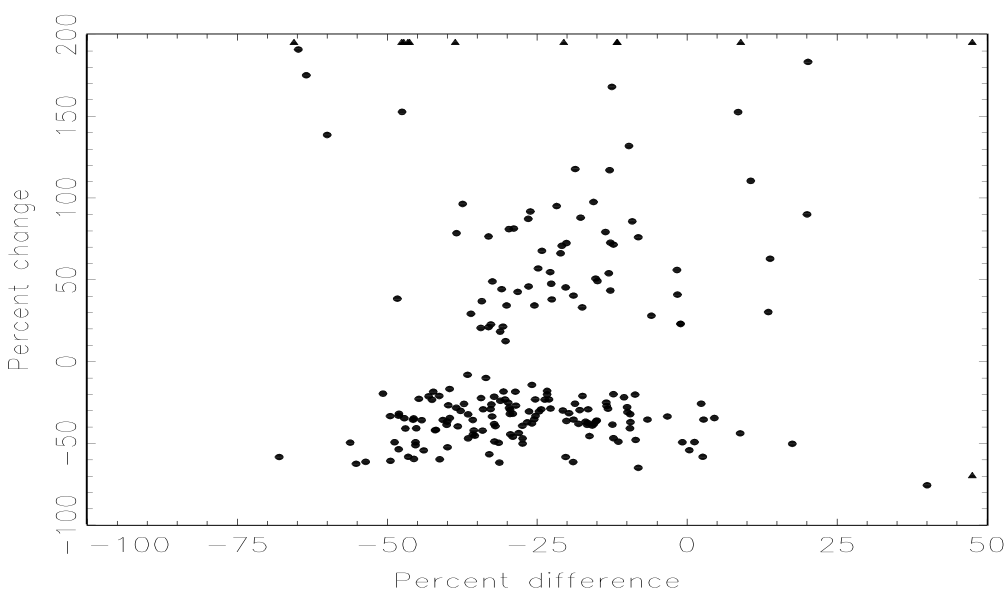


Figure 7: Scatter of percent difference in standard deviation during recessions and expansions (horizontal axis) and percent change in standard deviation during expansions (vertical axis) for all 215 series. Series for which the standard deviation during expansions is more than 50% higher than during recessions and series for which the standard deviation during expansions more than triples are shown as triangles.