# Changes in Variability of the Business Cycle in the G7 Countries*

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**Abstract**

Volatility breaks are tested and documented for 19 important monthly macroeconomic time series across the G7 countries. Across all conditional mean specifications considered, including both linear and nonlinear models with and without a structural break, volatility breaks are found to be widespread. This continues to hold when business cycle nonlinearities are allowed in the variance. Multiple volatility breaks are also examined, and these are found to be especially prevalent for short-term interest rates. Volatility breaks in industrial production and consumer prices are largely synchronous across the G7. The facts established are discussed in the context of some explanations put forward in the literature to explain volatility breaks previously found for US series.

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# 1 Introduction

Recent empirical evidence suggests that business cycle fluctuations in the US have dampened considerably over the last two decades. In particular, Kim and Nelson (1999), McConnell and Perez-Quiros (2000) and Koop and Potter (2000), among others, document a substantial reduction in the variability of US output growth in the early 1980s. McConnell, Mosser and Perez-Quiros (1999), Chauvet and Potter (2001) and Ahmed, Levin and Wilson (2001) show that the reduction in volatility of US GDP is shared by other important macroeconomic variables such as employment, consumption and income. Even more extensive evidence for a change in the variability of US economic fluctuations is provided by Sensier and van Dijk (2001), where a change in volatility is found to have occurred in a wide range of US macroeconomic variables during the period 1959-1996; see also Stock and Watson (2002).

In contrast to this burgeoning literature documenting the reduction in volatility for important macroeconomic time series for the US, relatively little attention has been paid to whether corresponding volatility reductions have been observed in other countries. Mills and Wang (2000), Blanchard and Simon (2001) and Smith and Summers (2002) examine the volatility of output (gross domestic product) growth in the G7 countries, and find that all seven economies have experienced a decline in output growth fluctuations, although the magnitudes and dates of the breaks differ across countries. Stock and Watson (2002) examine industrial production of the G7 countries, and document some breaks, in the context of their primary interest in US series. Taken at face value, the results across countries seem to imply that volatility breaks are essentially domestic phenomena, whose magnitude and timing depend on the specific conditions and policies in each country. Nevertheless, seeking for explanations in entirely domestic terms ignores the fact that volatility reductions have occurred in other countries.

A focus of interest in the US literature has been to uncover the explanation(s) for the dramatic reduction observed in output volatility. Kahn, McConnell and Perez-Quiros (2002) argue that improvements in inventory control through the use of information technology appears to be the main source of this reduction. Kim, Nelson and Piger (2001), on the other hand, emphasise the potential role for monetary policy changes since the early 1980s, see also Clarida, Galí and Gertler (2000) and Galí, López-Salido and Vallés (2002). Ahmed, Levin and Wilson (2001) and Stock and Watson (2002) consider these and other possible explanations, finding that the increased US macroeconomic stability can be attributed neither to "good business practice" nor to "good policy" but rather to "good luck", in the sense that the reduction in GDP growth volatility is primarily accounted for by a reduction in the variance of macroeconomic shocks.

In this paper we document a decline in volatility across a wide range of macroeconomic variables from each of the G7 countries. Although we do not investigate all possible explanations for this volatility change in detail, we establish that it is not primarily due to structural breaks in the conditional mean processes or to business cycle nonlinearities. Further, the communality of the break dates across countries for some series but not for others throws serious doubt on changes in monetary policy as being the main underlying factor leading to lower volatility across the G7.

The plan of the paper is as follows. In Section 2 we describe the data set used in our analysis and the tests for structural change in volatility. Section 3 contains the empirical results along with some discussion, with conclusions drawn in Section 4.

# 2 Data and Testing Methodology

## 2.1 Data

We examine a data set comprising the following key macroeconomic variables for each of the G7 countries: industrial production, index of leading indicators, retail sales, orders, new car registrations, unemployment rate, wages, unit labour costs, imports, exports, narrow and broad money measures, short- and long-term nominal interest rates, stock prices, exchange rates vis-à-vis the US dollar, producer prices, consumer prices, and terms of trade. Due to limitations in data availability, the total number of series in the data set is equal to 125. The data are monthly, with the sample period starting in January 1960[1] and ending in December 2000 (492 observations). All series except interest rates and unemployment rates are transformed to logarithms. Almost all real series are seasonally adjusted, although some financial ones (consumer price index, producer price index, interest rates, exchange rates, stock prices and terms of trade) are typically seasonally unadjusted. Seasonality in those series is accounted for by including seasonal dummy variables in all models to be discussed below. Outliers evident in some individual series have been interpolated. A detailed description of the data set is given in the Data Appendix.

[1] Although some series are not available from the beginning and in addition, to avoid the essentially flat exchange rates during the Bretton Woods period, the first observation used for exchange rates is January 1974.

## 2.2 Testing for Structural Change in Volatility

Our analysis is based upon tests for discrete changes in volatility in univariate autoregressive models for first differences (growth rates) of the series, which are denoted as $y_t$. Specifically, we consider the following four specifications for the conditional mean. First, we use a linear autoregressive (AR) model with constant parameters,

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

where $T$ denotes the sample size. Second, we allow for a single structural change in the parameters of a linear autoregressive (AR) model at time $\tau_m$,

$$\begin{aligned} y_t = {} & (\phi_{10} + \phi_{11} y_{t-1} + \ldots + \phi_{1p} y_{t-p}) \mathtt{I}(t \leq \tau_m) \\ & + (\phi_{20} + \phi_{21} y_{t-1} + \ldots + \phi_{2p} y_{t-p}) \mathtt{I}(t > \tau_m) + \varepsilon_t, \end{aligned} \tag{2}$$

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. The value of $\tau_m$ that minimizes the sum of squared residuals corresponding to (2) is taken to be the estimate of the break date. Third, we consider a nonlinear autoregressive model which allows for regime-switching between recessions and expansions,

$$\begin{aligned} y_t = {} & (\phi_{10} + \phi_{11} y_{t-1} + \ldots + \phi_{1p} y_{t-p}) \mathtt{I}(s_t = 0) \\ & + (\phi_{20} + \phi_{21} y_{t-1} + \ldots + \phi_{2p} y_{t-p}) \mathtt{I}(s_t = 1) + \varepsilon_t, \end{aligned} \tag{3}$$

where $s_t = 0\,(1)$ if calendar month $t$ is part of an expansion (recession), which are defined using the business cycle turning points provided by the Economic Cycle Research Institute.[2] Thus, the dates of the business cycle phases are treated as known, at least *ex post*, and exogenous. Fourth and finally, we employ a nonlinear autoregressive model which allows for regime-switching between recessions and expansions as well as a single structural change during expansions,

$$\begin{aligned} y_t = {} & [(\phi_{10} + \phi_{11} y_{t-1} + \ldots + \phi_{1p} y_{t-p}) \mathtt{I}(t \leq \tau_m) \\ & + (\phi_{20} + \phi_{21} y_{t-1} + \ldots + \phi_{2p} y_{t-p}) \mathtt{I}(t > \tau_m)] \mathtt{I}(s_t = 0) \\ & + [\phi_{30} + \phi_{31} y_{t-1} + \ldots + \phi_{3p} y_{t-p}] \mathtt{I}(s_t = 1) + \varepsilon_t. \end{aligned} \tag{4}$$

In principle, we would prefer to permit a structural change in the coefficients of (4) during recessions as well as during expansions. However, this would restrict $\tau_m$ to

[2] See `http://www.businesscycle.com`.

occur after the first observed business cycle regime shift for the specific country, which in practice typically means after the beginning of the recession in the mid-1970s. This is undesirable given the evidence from the US that breaks in the mean equation may have taken place early in the 1970s, see Stock and Watson (1996, 2002), and similar findings for the other G7 countries based upon the linear AR model with structural change in (2), as discussed below. This problem could be circumvented by allowing for independent structural changes in the coefficients of (4) during expansions and recessions. We did not consider this possibility, however, because of the relatively small number of recession observations available, which would imply very imprecise estimates of the model parameters.

In all four specifications for the conditional mean, we assume that $\varepsilon_t$ is a martingale difference sequence with time-varying conditional variance $\mathsf{E}[\varepsilon_t^2|\Omega_{t-1}] = \sigma_t^2$, where either a single structural change is allowed,

$$\sigma_t = \sigma_1 \mathtt{I}(t \leq \tau_v) + \sigma_2 \mathtt{I}(t > \tau_v), \tag{5}$$

or both regime-switching between recessions and expansions as well as a structural change during both business cycle phases,

$$\sigma_t = (\sigma_1 \mathtt{I}(t \leq \tau_v) + \sigma_2 \mathtt{I}(t > \tau_v))\mathtt{I}(s_t = 0) + (\sigma_3 \mathtt{I}(t \leq \tau_v) + \sigma_4 \mathtt{I}(t > \tau_v))\mathtt{I}(s_t = 1), \tag{6}$$

where $\Omega_{t-1}$ is the information set at time $t$ consisting of lagged values of $y_t$ and $\varepsilon_t$.

In both (5) and (6), we test for changes in the conditional variability as follows. First consider the specification in (5), and let $F_T(\tau_v)$ denote a Likelihood Ratio (LR), Lagrange Multiplier (LM) or Wald (W) statistic of the hypothesis of constant conditional standard deviation, that is $\mathsf{H}_0 : \sigma_1 = \sigma_2$, for break date $\tau_v$. 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 $F_T(\tau_v)$ for $\tau_v = \tau_1, \tau_1 + 1, \ldots, \tau_2 - 1, \tau_2$. Specifically, we consider the supremum, average and exponential statistics, given by

$$\text{SupF} = \sup_{\tau_1 \leq \tau_v \leq \tau_2} F_T(\tau_v), \tag{7}$$

$$\text{AveF} = \frac{1}{\tau_2 - \tau_1 + 1} \sum_{\tau_v = \tau_1}^{\tau_2} F_T(\tau_v), \tag{8}$$

$$\text{ExpF} = \ln \left( \frac{1}{\tau_2 - \tau_1 + 1} \sum_{\tau_v = \tau_1}^{\tau_2} \exp\left( \frac{1}{2} F_T(\tau_v) \right) \right), \tag{9}$$

where F=LR, LM or W.

In the specification in (6), which allows for different conditional variances in different business cycle phases in addition to a structural change, we test for constancy of the conditional variance in recessions and expansions jointly and separately. That is, we test the null hypotheses

$$\begin{aligned}\mathsf{H}_0^{(j)} &: \sigma_1 = \sigma_2 \text{ and } \sigma_3 = \sigma_4,\\ \mathsf{H}_0^{(e)} &: \sigma_1 = \sigma_2 \text{ assuming } \sigma_3 = \sigma_4,\\ \mathsf{H}_0^{(r)} &: \sigma_3 = \sigma_4 \text{ assuming } \sigma_1 = \sigma_2.\end{aligned}$$

Thus, in testing constancy of the conditional volatility during expansions only ($\mathsf{H}_0^{(e)}$), we assume that the conditional volatility during recessions does not experience a structural change and *vice versa*. Note that, as discussed above, a joint test such as $\mathsf{H}_0^{(j)}$ suffers from the restriction that the break cannot be dated prior to the first business cycle phase shift in the sample period. Consequently, we concentrate on the results for the separate tests of $\mathsf{H}_0^{(e)}$ and $\mathsf{H}_0^{(r)}$.[3]

All volatility break tests are implemented by regressing $\sqrt{\frac{\pi}{2}}|\hat{\varepsilon}_t|$ on appropriate dummy variables, cf. McConnell and Perez-Quiros (2000), where $\hat{\varepsilon}_t$ are the residuals from one of the four models for the conditional mean as given in (1)-(4).[4] The value of $\tau_v$ that minimizes the sum of squared residuals in these regressions is taken to be the estimate of the break date for the conditional volatility. Confidence intervals for the break dates are computed using the methods developed in Bai (1997a).[5] We compute all 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. The asymptotic distributions of the SupF, AveF and ExpF statistics are non-standard and have been derived by Andrews (1993) and Andrews and Ploberger (1994). Throughout the paper we use the method of Hansen (1997) to obtain approximate asymptotic $p$-values.

In addition to single breaks, as in equations (5) and (6), we also test for multiple breaks in volatility using the sequential procedure of Bai (1997b); see also Bai and

[3]Note that we do test for a structural change in volatility during recessions, as opposed to the conditional mean specification given in (4). The problem of having relatively few observations during recessions is less severe in this case, as only a single parameter before and after the structural change needs to be estimated, in contrast to $p+1$ parameters in the AR model for the conditional mean.

[4]If $\varepsilon_t$ follows a normal distribution, $\sqrt{\frac{\pi}{2}}|\hat{\varepsilon}_t|$ is a unbiased estimator of the standard deviation of $\varepsilon_t$.

[5]When computing these confidence intervals we take into account the fact that, in the presence of a structural change, the variance of the error term in the test regression is different before and after the break, cf. Stock and Watson (2002). This results in asymmetric confidence intervals, with less uncertainty about the break date in the high than the low volatility period.

Perron (1998). After detecting a single volatility break, the procedure is to split the sample at that date and to perform the break test separately on each sub-sample. If a further significant volatility break is detected, the procedure is repeated. Sample splitting stops when a maximum of five breaks is detected, or when the subsamples become too small for further splitting. Finally, the dates of each of the $m$ detected breaks are re-estimated one by one, conditional on the dates of the remaining $m-1$ breaks obtained in the sequential procedure. Throughout these procedures, a minimum of 15% of the sample is required to lie between consecutive breaks. Multiple volatility break tests are performed using all four conditional mean models of (1) to (4). Due to limitations on the available sample sizes in expansions and especially recessions, multiple breaks are considered only as direct generalisations of (5) rather than in the context of the nonlinear conditional volatility model of (6).

Finally, the order of the AR models for the conditional mean is determined by applying the Akaike Information Criterion (AIC) in (1), with the maximum order set equal to $p_{\max} = 12$. To prevent remaining residual autocorrelation influencing the results from the structural change tests, 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 order thus selected is also used in the remaining specifications (2)-(4) for the conditional mean.

# 3 Empirical Results

We consider first the baseline specification using model (1) for the conditional mean and testing constancy of the conditional standard deviation against the alternative specification given in (5). Results are discussed in section 3.1. To guard against the possibility that the breaks for conditional volatility thus found are spurious artefacts of neglected breaks or nonlinearities in the conditional mean equation, we report results for the more general specifications of equations (2) to (4) in section 3.2. The possibility that apparent volatility breaks are in fact associated with business cycle nonlinearities in volatility is discussed in section 3.3, while multiple breaks are considered in section 3.4. The implications of the complete set of empirical results are discussed in section 3.5.

## 3.1 Baseline Specification

In the baseline linear specification, a significant change in volatility is detected for 81.6% of the series considered using the SupW statistic,[6] while the median change in the standard deviation is equal to −34.5%, see the second and third columns in Table 1. Panel (a) of Figure 1 contains a histogram of the percent change in standard deviations for the 102 series for which the SupW statistic is significant at the 5% level. For 70 series, the change is negative, indicating that in general volatility has declined. Panel (b) of Figure 1 shows a histogram of the break dates obtained from the SupW statistic, again for the series for which the statistic is significant at the 5% level. It is seen that the instability occurs fairly uniform across the sample period, although there is some concentration of break dates around the end of the 1970s, 1983-1984 and 1991. The scatter plot of the break dates against the percent change in standard deviation in panel (c) of Figure 1 suggests that there may be a negative relation between the timing and magnitude of the change in volatility. Indeed, the correlation between the break date and percent change in standard deviation is equal to −0.26.

Results for individual series are detailed in Appendix Table A.1. One feature of these results, not evident in the summary tables, is the very low marginal significance level achieved in many cases. The SupW test for a volatility break is significant at the 0.01% level for a total of 64 series, or just over half of the total number considered. Of these, 50 have experienced a volatility decline and 14 an increase.

**- insert Table 1 and Figure 1 about here -**

Volatility changes have occurred in each of the G7 countries, although Table 1 indicates that there are some differences in the extent of these changes. For Canada and Germany, the null hypothesis is rejected for just under three quarters of the variables considered, whereas for the UK a change in volatility is suggested for all but one of the 19 variables. The median change in standard deviation also varies considerably, ranging from an increase of 2.8% for Canada[7] to reductions of 40% for France and Japan. Figure 2 contains country-specific scatter plots of the break dates against the percent change in standard deviation, including 90% confidence intervals for both. These plots demonstrate that also the timing of the change in

[6]Results for the other test statistics are very similar throughout and are available upon request.

[7]The median change in standard deviation for Canadian series is so close to zero because the SupW statistic is significant at the 5% level for 14 series, of which 7 have experienced a decline in volatility and 7 an increase.

variability varies across and within countries. The break dates are concentrated in the first half of the 1980s for the US and, to a lesser extent, Canada and France, while for the UK the break dates are grouped in two clusters, in the early 1980s and early 1990s. In contrast, there are no periods with a large concentration of break dates for Germany, Italy and Japan.

**- insert Figure 2 about here -**

Table 2 provides evidence on the extent of volatility changes across types of series, with the results in the second and third columns relating to the baseline specification. Overall, real variables exhibit volatility reductions, with those for industrial production, the leading indicator index, retail sales and new car registrations being widespread among the G7. Note that, although the volatility reduction in US employment documented by Warnock and Warnock (2001) as occurring during the 1980s is reflected here in reduced volatility for US unemployment, no other G7 country experiences a corresponding significant reduction for this variable. Further, the significance of the reduction in US unemployment volatility is much less marked than that experienced for, say, US industrial production or retail sales (Appendix Table A.1).

**- insert Table 2 about here -**

Turning to monetary/financial variables, Table 2 indicates two distinct groups. The first consists of wages, short-term interest rates, consumer prices and the terms of trade and, to a lesser extent, unit labour costs and producer prices. In common with the real variables, these predominantly show reduced volatility. This is also true for both imports and exports, which are nominal series[8]. The second group, consisting of narrow and broad money, long-term interest rates, stock prices and the exchange rate, have positive median volatility changes across the G7. Within this group, increases in volatility dominate for long-term interest rates, stock prices and exchange rates (with the series for at least two thirds of available countries significant at 5%).

**- insert Figure 3 about here -**

[8]Ideally we would have liked to study import and export volumes, rather than nominal series. Although these are available quarterly, the relevant price deflators are not available at the monthly frequency for most of the countries and period studied here.

To examine the communality of volatility changes for specific variables across the G7 countries, Figure 3 presents scatter plots (with confidence intervals) for the break dates against the percent change in standard deviation for selected key macroeconomic variables for cases where significant changes in volatility are indicated by the SupW statistic at the 5% level applied to the baseline linear specification. The series included in this figure reflect the state of the business cycle (through industrial production and retail sales), trade, wage and price inflation, and interest rates (long-term and short-term). The first panel of this figure shows that all significant changes in industrial production volatility have estimated break dates between 1984 and 1990. Where the break takes place at the end of the 1980s or the beginning of the 1990s, namely in Italy, France and the UK, the confidence intervals for the break dates are tighter than for the early 1980s breaks for Canada and the US.[9] The confidence intervals for the magnitude of the reductions are, however, very similar. Panel (b), relating to retail sales, shows little evident pattern across countries in either the date or the magnitude of the break. Nevertheless, it is noteworthy from Table A.1 that the breaks for Canada, the UK and the US in retail sales are effectively synchronous with the breaks in industrial production for these countries. For both of these business cycle variables, the 90% confidence intervals often cover around five years, and hence the estimated break dates should be treated with some caution.

The estimated break dates for imports are clustered in the second half of the 1980s and the beginning of the 1990s, with those for exports more diverse in date but generally a little earlier. However, in this latter case some confidence intervals are very wide, covering up to thirteen years.

Volatility breaks have different characteristics for wage versus price inflation, despite the fact that all five wage series and six out of seven consumer price series exhibit significant breaks. For wages, volatility reductions are dated between 1975 and 1984, but there is a significant increase in one case (Canada) dated in 1994. In contrast, the significant breaks in consumer price inflation are effectively synchronous across countries, as they are estimated to have occurred in the narrow time period between 1981 and 1984. However, some confidence intervals for the break date, including those for the UK and the US, cover up to eight years.

There has been much discussion about the role of monetary policy in reducing

[9] Our findings concerning the significance and timing of the change in volatility of the IP series correspond with the results reported by Stock and Watson (2002) for Germany, Japan, and the US. By contrast, Stock and Watson (2002) do not find evidence for a change in conditional volatility for Canada and France, while they date the breaks for Italy and the UK in 1983 and 1985, respectively.

output volatility in the US (Kahn *et al.* 2001, Kim *et al.* 2001, Stock and Watson, 2002). However, in contrast to the relatively concurrent break dates for industrial production, the break date estimates for the short-term interest rates across the G7 span the period 1977 to 1993. With the exception of Canada, which has a substantial increase in volatility from 1979, all countries show reductions of around fifty percent in the volatility of short-term interest rates. This break is dated to occur as late as 1993 for the UK. There is a stark contrast between short-term and long-term interest rates, with all seven countries having increases in the volatility of long-term rates of at least 100% between 1969 and 1979. Indeed, the confidence intervals for the break dates for long-term interest rates are quite tight, covering at most 30 months. This markedly different behaviour of short-term and long-term interest rates corroborates the findings of Watson (1999) for the US.

## 3.2 Conditional Mean Changes and Volatility Breaks

There is considerable evidence for structural change and nonlinearity in the conditional mean dynamics of macroeconomic variables, see Stock and Watson (1996, 2002) and Marcellino (2002), among others. For our data, note first that, using a SupW test, parameter constancy in the AR($p$) model (1) is rejected against the presence of a single structural change as in (2) for 58.4% of the series considered, see the second column of Table 3. Structural change is widespread among Japanese series (84.2% rejections), whereas it is relatively rare among German series (27.8%). The second column of Table 4 shows that the evidence for structural change also varies widely across types of series: wages, unit labour costs, consumer prices, producer prices and short-term interest rates have experienced breaks in almost all countries, while there is very little or no evidence for such structural change in stock prices and exchange rates.

Panel (a) of Figure 4 shows a histogram of the conditional mean break dates obtained from the SupW statistic for the series for which the statistic is significant at the 5% level. It is seen that the break dates are concentrated around 1974 and 1980. Although this detailed information is not included, closer inspection of these break dates reveals that there are noteworthy differences across countries. For example, for France, Italy and Japan more than half of the significant changes occur around 1974, while for Germany, UK and US this is the case around 1980. Finally, for Canada changes occur uniformly across the sample period.

**- insert Tables 3 and 4 and Figure 4 about here -**

Second, the third column of Table 3 shows that the linear AR model is rejected against the nonlinear alternative (3) for almost half of the series considered, using a standard Wald test. Again, the evidence for nonlinearity varies considerably across countries, ranging from 25% for France to 76.5% for the US. Substantial variation can also be observed across groups of series, see the third column of Table 4, with little or no evidence for business cycle nonlinearity in money, stock indices, exchange rates and exports and, not surprisingly, ample evidence in industrial production, unemployment and consumer price series.

Third, in the nonlinear model (3) parameter constancy within expansions is rejected for 52.8% of the series, see the fourth column in Table 3. Here, more than three quarters of Japanese series exhibit significant structural change in the conditional mean, while the lowest percentage relates to Germany and is less than 40% of the series considered. The patterns across series are generally similar to those for breaks in the linear autoregressive model (compare the second and fourth columns of Table 4), although the use of the nonlinear model yields additional evidence of structural breaks in the conditional mean equation for retail sales and exports, but less for unemployment, unit labour costs and producer prices. Panel (b) of Figure 4 shows a histogram of the break dates obtained from the SupW statistic for the series for which the statistic is significant at the 5% level. Compared to the break dates obtained when testing for a structural change within the linear model, it is seen that the break dates now are more evenly spread across the sample period.

The fourth to ninth columns of Tables 1 and 2 show detailed results per country and per group of series on the extent of changes in conditional volatity in the context of these more general conditional mean models. There is a modest reduction, from 82% to around 76%, in the total number of series for which significant volatility breaks are found when a single structural change is allowed in the mean equation of either the linear or nonlinear model. Even in the most general model, allowing nonlinearity over the business cycle and a single structural break in the coefficients, more than 60% of series for each G7 country show significant structural breaks in volatility. The most notable change over the models in Table 1 relates to Canada, where allowing for a single structural break in the mean, in either a linear or nonlinear model, causes the average volatility change to be negative rather than positive. Across series, the leading indicator and exports provide the only examples where the number of countries with breaks in volatility changes by more than one in the general model of (4) compared with the baseline linear and time-invariant AR($p$) specification of (1). Therefore, these tables provide evidence that our results on the extent of volatility change are not driven by neglected structural change or business cycle asymmetry in the conditional mean.

Figure 5 shows histograms and a scatter plot of the percent changes in standard deviation and break dates, when using the most elaborate model (4) for the conditional mean with specification (5) for the conditional standard deviation. In comparison with the corresponding information for the baseline linear model in Figure 1, the distribution of the magnitude of the change in the standard deviation is largely unaffected, while the distribution of the break dates appears to be a little more uniform, although with some concentration in the early 1980s. Figures 6 and 7 show corresponding scatter plots by country and by specific series for the volatility break dates against the percent change in the standard deviation. In comparison with Figure 2, the patterns of volatility breaks across countries is generally similar, although patterns are now more evident for France and the UK. With the single exception of an increase in volatility for the long-term interest rate, all volatility breaks for France in Figure 6 are negative and most are estimated to occur in the first half of the 1980s, while all but one of the volatility reductions for the UK are estimated to take place either in the first half of the 1980s or early 1990s. Volatility breaks remain concentrated in the years between 1984 and 1991 for industrial production, while the break dates for import volatility are now narrowly confined to the three years 1986 to 1988. In contrast, volatility breaks for consumer prices are considerably more dispersed in the general model (4) than in the context of the linear model. As for the linear model, however, many confidence intervals over all series cover periods of ten years or more.

**- insert Figures 5 to 7 about here -**

Finally, it is of interest to compare the estimated break dates for a change in the parameters of the model for the conditional mean and for a change in the conditional standard deviation. Across all 125 series, there is essentially no relationship between the two break dates, with correlations equal to 0.08 and 0.11 if structural change is allowed in the linear and nonlinear model, respectively. These correlations increase to 0.14 and 0.13, respectively, if attention is restricted to those series for which the SupW test for structural change in the conditional variance are significant at the 5% level. If, in addition, it is required that the SupW test is significant at the 5% level as well, the correlations further increase to 0.22 and 0.38, respectively. Although not overwhelming, this does suggest some relationship between breaks in the conditional mean and variance properties of these series.

### 3.3 Volatility Nonlinearities and Breaks

The volatility of macro-economic variables tends to be larger during recessions than during expansions, see Brunner (1992), French and Sichel (1993), and Warnock and Warnock (2000), among others. To control for this feature and to examine whether the detected changes in variability have occurred primarily in either recessions or expansions, we test for changes in volatility using specification (6) for the conditional standard deviation in combination with each of the four conditional mean specifications of (1)-(4).

First, to examine the extent of nonlinearity in volatility, we apply a Wald test for equality of the conditional standard deviation across recessions and expansions. The results in Tables 5 and 6 reveal that linearity can be rejected for at least 40% of the series irrespective of the model used for the conditional mean. In the linear AR($p$) model the standard deviation in recessions is 46% higher than during expansions on average, with this being reduced to 33% higher in the nonlinear model of (3). Although allowing a single structural change in the mean equation has little overall effect on volatility nonlinearities, it is not surprising that the magnitude of the volatility difference between recessions and expansions tends to be reduced when nonlinear dynamics are allowed in the mean.[10] Comparison with the evidence in Tables 1 and 2 for structural breaks in volatility using these models reveals that volatility breaks are substantially more widespread than volatility nonlinearities associated with the business cycle.

**- insert Tables 5 and 6 about here -**

According to Tables 5 and 6, there is considerable variation in both the rejection frequency of linearity and the magnitude of the difference in variability over business cycle phases, whether examined across countries or across groups of series. For example, nonlinearity in variance is detected for only 18.8% of the French series, while it is found in almost 90% of the US series when a linear mean specification is used. It is interesting to note that, whereas the overall evidence for nonlinearity in variance is fairly constant across different specifications for the conditional mean, it varies considerably for individual countries. For Canada, Germany and the US, the percent rejections declines substantially when more elaborate models are used,

[10]It is also interesting to note that, of the 57 (50) series for which the Wald test for nonlinearity in volatility is significant at the 5% level when using the linear model (with structural change), only 2 (2) have lower volatility during recessions than during expansions. If nonlinearity is allowed for, this number increases to 11 (8) out of 50 (52).

especially when allowing for nonlinearity in the conditional mean. By contrast, for Japan the percent rejections increases to about 40% with the nonlinear specifications (3) and (4) compared to slightly more than 20% when using the linear models (1) and (2). Volatility nonlinearities are particularly widespread among the G7 for consumer and producer prices, and for interest rates, especially long-term ones. Perhaps surprisingly, once nonlinearities are allowed in the mean, only one or two countries continue to show evidence for volatility nonlinearities for the key business cycle variables of industrial production, retail sales and unemployment. Particularly in relation to these key variables, nonlinearities in the mean (see also column 3 of Table 4) are more widespread than nonlinearities in the variance.

Second, we test for volatility breaks allowing for volatility nonlinearity, with Tables 7 and 8 containing detailed statistics for the "separate" tests[11] corresponding to $\mathsf{H}_0^{(e)}$ and $\mathsf{H}_0^{(r)}$ discussed in section 2.2. Perhaps because a greater number of expansion than recession months are observed over our sample period, we find more evidence for changes in volatility during expansions than during recessions: the number of series for which the corresponding null hypothesis is rejected being equal to 90 and 64, respectively, for the linear mean model. On the other hand, the magnitude of the change in volatility is generally larger during recessions: the median percent changes in standard deviation in this model are equal to −34.3% and −53.8% for expansions and recessions, respectively. These overall statistics are essentially invariant to the particular specification of the mean in equations (1) to (4). When considered by country, however, there are sometimes differences depending on the mean specification, with these being particularly marked for the US. In particular, during recessions US volatility breaks vary in extent from 40% to 70% of series and from substantial volatility increases using the linear specifications of (1) and (2) to median changes representing declines of 50% or more using the corresponding nonlinear specifications. One notable feature of Table 8 is that the median volatility increases noted in section 3.1 for narrow and broad money, long-term interest rates, stock prices and exchange rates are, with the single exception of the last of these, apparently due to expansion periods only, since volatility changes during recessions are negative on average.

**- insert Tables 7 and 8 about here -**

Figure 8 shows histograms and scatter plots of the percent changes in standard deviation during expansions and recessions and corresponding break dates, in the

[11] The "joint" test $\mathsf{H}_0^{(j)}$ yields similar results to those reported for the expansions break test $\mathsf{H}_0^{(e)}$.

context of the nonlinear conditional mean model with a structural break of (4). For both business cycle phases but especially for recessions, the large majority of variables for which a change in volatility is indicated have experienced a decline in volatility. To be precise, of the 91 (54) series for which the SupW test for a change in volatility during expansions (recessions) is significant at the 5% level, the change in volatility is negative for 62 (46) series. Histograms of the break dates, shown in panels (c) and (d) of this figure, indicate a fairly uniform distribution of volatility changes in expansions, while those for recessions are particularly clustered during the early 1980s recessions. The scatter plot in panel (e) suggests that increases in volatility during expansions are largely confined to the period prior to 1980, with volatility decreases dominant after that date.

**- insert Figure 8 about here -**

Figures 9 to 12 contain confidence intervals for the break dates and the percent changes in standard deviation during expansions and recessions separately for both countries and selected types of series. Even considering expansion and recession regimes separately in this general mean specification of (4), experiences differ across countries. Volatility breaks dated during expansions for this model are qualitatively similar to the volatility breaks seen earlier in Figures 2 and 6. However, it may be noted that the more general models provide additional evidence of volatility increases for some US series prior to 1980. One striking feature of dating volatility breaks specifically for recessions is that recessions at different periods are important for different countries, see Figure 10. Specifically, Japanese series show significant volatility breaks during the mid-1970s recession, while those in Canada and the UK tend to be clustered during the recession of the early 1980s in the respective countries. Due to the scarcity of breaks during recessions when considered by series, little can be said about about Figure 12. However, the corresponding information relating to breaks during expansions for selected series in Figure 11 emphasises the communality of break dates and magnitudes across the G7 for industrial production, imports, consumer prices and, to a lesser extent in terms of dates, long-term interest rates; cf. Figures 3 and 7. A corresponding communality is not evidenced by retail sales, exports, wages or short-term interest rates.

**- insert Figures 9 to 12 about here -**

## 3.4 Multiple Breaks

The extent of breaks in volatility across G7 series, documented in subsections 3.1 to 3.3, raises the possibility that individual series may experience more than one break over the forty year period examined. Tables 9 and 10 provide evidence on this, in the context of the nonlinear specification with a single structural break for the mean, namely equation (4)[12]. Overall, a third of our series (41 of the 125) evidence multiple volatility breaks, with 7% having three breaks. Multiple breaks are particularly common in the US and UK, where around half of all series show this feature. By series, multiple breaks are prevalent among nominal monetary/financial series, especially short-term interest rates. In contrast, there is little evidence for multiple volatility breaks among the concurrent business cycle indicators of retail sales and industrial production. Despite volatility breaks in retail sales being widespread across the G7, no country shows more than one volatility break for this series. Based on results for industrial production, only Italy experiences more than one break in business cycle volatility (in 1970 and 1985).

**- insert Tables 9 and 10 about here -**

A feature of allowing multiple breaks is the striking consistency across both countries and series of the magnitude of the overall decline in volatility; see columns 8 and 9 of these tables. By country and considering (as before) cases where there is a volatility break significant at the 5% level, the net decline in volatility from prior to the first break until subsequent to the last is, with the single exception of Germany, close to 25%. In contrast to Table 2, where some monetary/financial series show increases, all groups of series with significant volatility breaks in Table 10 show net declines in volatility of between approximately 25% and 35%. Therefore, the pattern of volatility increases noted in relation to a group of monetary/financial variables in Table 2 appears to be largely a temporary phenomenon, as documented for many nominal US series by Sensier and van Dijk (2001).

The scatter plot of break dates against volatility changes in panel (a) of Figure 13 considers the total of 147 breaks uncovered by this analysis of multiple breaks.[13] In comparison to the corresponding scatter plot of Figures 1 and 5, the negative

[12]Results for other conditional mean specifications show similar characteristics to those reported here.

[13]Histograms of the percent change in standard deviation and break dates for multiple volatility breaks are qualitatively similar to those shown for the case of a single break in panels (b) and (c) respectively of Figures 1 and 5.

relationship between the value and date of the break is now more apparent, with the simple correlation between these being $-0.41$. Since 1980 appears to be a watershed after which increases in volatility become relatively rare, the final four columns of Tables 9 and 10 divide the volatility breaks at this date. Prior to 1980, the median volatility change is an increase of 63%, including a median increase in long-term interest rate volatility of 137%. Considered from 1980 onwards, the median volatility decline for every G7 country other than Canada is at least 30%. By series, only broad money, stock prices and exchange rates show median volatility increases after 1980.

**- insert Figure 13 about here -**

It was noted above that multiple breaks are particularly prevalent for short-term interest rates in the G7, with the characteristics of these indicated by panel (b) of Figure 13. The distinctive features of the pre-1980 and post-1980 periods are particularly apparent in this plot, with five out of seven volatility changes in the earlier period being positive but all ten individual changes during the later period negative. Indeed, the pre-1980 volatility increases generally have relatively tight confidence intervals for the break date but relatively wide intervals for the magnitude of the break, with the opposite characteristics typically applying for the post-1980 breaks. All G7 countries except France are found to have at least one signficiant volatility break in the period before 1980 (with the US having two), and only those for Germany and Italy are declines. Canada, France, Japan and the UK all experience two significant declines in short-term interest rate volatility after 1980, with one between 1981 and 1986 and a second larger one in the period 1993-6.

## 3.5 Discussion

The volatility properties of output growth have been widely studied for the US, and in lesser detail for the G7 countries (Mills and Wang, 2000, Blanchard and Simon, 2001, Smith and Summers, 2002, Stock and Watson, 2002). A remarkable finding of the extensive analysis undertaken in this paper is that the dates and magnitudes of the breaks in industrial production growth largely concur across the G7. This fact, in combination with our results for other major variables, challenges some of the explanations previously put forward to explain the US facts.

Some authors, including Ahmed, Levin and Wilson (2001) and Stock and Watson (2002), attribute the decline in US volatility to "good luck", namely to a decline in the volatility of (unexplained) shocks to the real macroeconomy. If this is the case, then our results imply that all G7 countries enjoyed similar strokes of good luck, especially in the period after 1980. However, the concurrence of the breaks in industrial production volatility suggest that there is a deeper explanation of the declines seen across these countries. We also date declines in import volatility during the same period as for industrial production. Although the US analysis of McConnell, Mosser and Perez-Quiros (1999) suggests that the decline in trade volatility is insufficient to explain that for output, this does not rule out a common underlying explanation across both variables.

Kahn, McConnell and Perez-Quiros (2001) discuss the potential role of improved inventory control in the increased stability observed for the US. Although their analysis focuses specifically on durable goods, whereas we analyse total industrial production and retail sales data, their observation that reductions in output volatility do not have corresponding sales volatility reductions carries over to our data. However, it must be stressed that we do find volatility reductions in retail sales growth to be widespread across the G7, but these occur at various dates between the mid-1970s and mid-1990s. Further, we find that volatility reductions in output, sales and trade volume variables are not reflected in reductions in unemployment volatility, whether concurrently or not. This could indicate a changing relationship between production and sales on the one hand and employment variables on the other. While a changing relationship of this type does not preclude a potential role of improved inventory control, it does suggest that productivity could also be important. Stock and Watson (2002) find evidence for productivity shocks playing a role in the US context. Since neither inventory control nor productivity changes are modelled directly in a typical macroeconomic system, their effects can be captured only indirectly and will be attributed largely to shocks. This adds plausibility to an explanation of the volatility decline in output lying at least partly in productivity changes and possibly inventory control, especially in the context of the highly industrialised countries of the G7. Although Hansen (2001) finds the strongest evidence for breaks in US productivity in the early 1990s (rather than the 1980s when volatility breaks predominantly occur), further examination of these seems to be warranted in the context of their impact on volatility changes.

A widely studied potential explanation for the decline in output volatility for the US is that of improved monetary policy; among others, this is examined by Kim, Nelson and Piger (2001) and Stock and Watson (2002). At one level, informal support for this explanation is provided in our results by the clustering of break dates for inflation volatility across the G7, like those for industrial production growth, during the first half of the 1980s. Nevertheless, we find much evidence for multiple breaks in short-term interest rate volatility, with increases prior to 1980 and decreases subsequently. There is no corresponding evidence for multiple breaks in output volatility. The differing break dates for short-term interest rates reflect different monetary policy regimes pursued by the G7 countries across the period from 1960, but there is no evidence that these monetary policy changes are generally associated with changes in output volatility.

Perhaps surprisingly, and in contrast to short-term interest rates, we do not find evidence of widespread multiple changes in consumer price volatility. Rather than in monetary policy itself, it is therefore possible that elements of the explanation for volatility reductions in real variables around the 1980s may be found through a study of the (possibly related) volatility decline in consumer price inflation observed across the G7. Although Blanchard and Simon (2001) make a similar point in the context of the correlation between GDP and inflation volatility in the G7 countries, this remains largely unexplored.

Across all specifications considered, we find that many 90 percent confidence intervals for the dates of volatility breaks are relatively wide, covering periods of around ten years or more. The obvious and plausible implication is that volatility breaks frequently occur smoothly over time rather than abruptly occurring at a specific date; see also Blanchard and Simon (2001). Despite Stock and Watson (2002) favouring their representation as an abrupt break, it is difficult to rationalise why a specific and apparently uneventful period, such the first quarter of 1984, should herald a discrete volatility reduction for real US macroeconomic time series.

# 4 Concluding Remarks

Our results establish that volatility breaks now widely documented for US time series have generally been experienced across the G7 countries. More specifically, declines in the volatility of the growth in real series, documented for the US by Kim and Nelson (1999), McConnell and Perez-Quiros (2000), Kim, Nelson and Piger (2001), Sensier and van Dijk (2001), and Stock and Watson (2002) among others, are widespread across the G7. Further, the increase (decrease) in volatility of US long-term (short-term) interest rates for the period from 1980, documented by Watson (1999), is uniform across all G7 countries. Indeed, the finding of Sensier and van Dijk (2001) that increases in volatility have also occurred for monthly US money and exchange rate series are generally reproduced here for the G7 countries. On the other hand, the decline in US employment volatility studied by Warnock and Warnock (2000) is not generally reproduced in other countries, at least when examined from the perspective of the unemployment rate.

Although we document the importance of business cycle nonlinearities in the mean and variance and of structural breaks in the conditional mean equation, the volatility changes found in our analysis are largely invariant to specifications that allow for these effects. Therefore, these volatility changes are not a by-product of fewer recession observations in the latter part of the sample, for example. Nevertheless, when the presence of volatility breaks is tested separately for expansions and recessions, the latter point up the possibility that specific postwar recessions have been important in this context for different countries. Further study into the role of breaks during specific recessions for the overall volatility decline is warranted.

Another issue worthy of further research is whether volatility changes are smooth or abrupt. As no specific event appears to have yet been identified that might be associated with a discrete volatility reduction in macroeconomic series, we believe that future research should consider further the possibility of smoothly changing volatility, without restricting this smooth change to have a linear form. Further light might also be shed by considering the possibility of common (smooth or discrete) breaks across multiple series, using the methods developed in Bai, Lumsdaine and Stock (1998) and building on the analysis of Stock and Warson (2002). This appears to be a promising avenue in an international context for some series, including industrial production and inflation, for which the break dates from the univariate models are fairly close.

We also document the extent and magnitudes of multiple volatility breaks. We find those prior to 1980 to be generally increases, with declines dominant after that date. Short-term interest rates exhibit multiple breaks in most countries of the G7, with the pattern just noted for the earlier and later sub-periods being especially pronounced for this variable. However, many other important variables (including industrial production, retail sales and consumer prices) do not typically exhibit multiple volatility breaks between 1960 and 2000.

Our results on the pattern of dates and magnitudes of breaks for different series across the G7 seem to imply that at least part of the explanation for the general decline in volatility lies with factors influencing industrial production growth and consumer price inflation. Due to substantial differences in dates for breaks in short-term interest rate volatility, we suggest that improved monetary policy is implausible as the principal explanation across these countries.

# Data Appendix

This appendix provides details on the series used in the empirical analysis. All series are extracted from Datastream (DS in the "Source" column below), where series from the OECD are used whenever available, except for some UK and US series that were obtained from the Office of National Statistics (ONS) and the Federal Reserve Bank of St. Louis (FRED), respectively. "Series Name" provides the acronyms used in the Table A.1, followed by the available sample period. The final column provides a brief description of the series. Financial series (interest rates, stock prices, and exchange rates) obtained from Datastream and the OECD are monthly averages of daily values, unless indicated otherwise. (Results obtained with corresponding end-of-period series are qualitatively similar to those reported in the paper.) The following abbreviations are used: SA=seasonally adjusted, NSA=not seasonally adjusted, TR=Trend Restored, EP=End of Period, MAV=Monthly Average.

| Series Name | Sample Period | Source | Description |
|---|---|---|---|
| | | | **Canada** |
| CAIPSA | 1961.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| CALIND | 1960.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| CARSALE | 1961.1-2000.12 | OECD | Retail Sales (volume index, 1995=100, SA) |
| CAORDER | 1960.1-2000.12 | OECD | New Orders: Manufacturing (MIL C$, SA) |
| CANCARR | 1960.1-2000.12 | OECD | New Passenger Car Registrations (SA) |
| CAUNEMP | 1960.1-2000.12 | OECD | Unemployment Rate (% of Civil Labour Force, SA) |
| CAWAGES | 1960.1-2000.12 | OECD | Wage Earnings: Manufacturing, Hourly (1995=100, SA) |
| CAULCOS | 1961.1-2000.12 | OECD | Unit Labour Costs: Manufacturing (1995=100, SA) |
| CAIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL C$, SA) |
| CAEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL C$, SA) |
| CANMONS | 1960.1-2000.12 | DS | Money Supply: M1 (MIL C$, SA) |
| CABMONS | 1968.1-2000.12 | DS | Money Supply: M2 (MIL C$, SA) |
| CASIRAT | 1960.1-2000.12 | DS | 3-Month Treasury Bill Tender Rate (EP) |
| CALIRAT | 1960.1-2000.12 | DS | Government Bond Yield: Over 10 Years (EP) |
| CASTOCK | 1960.1-2000.12 | OECD | Stock Index: TSE 300 Composite |
| CAEXRAT | 1974.1-2000.12 | DS | Canadian Dollar To US$ |
| CACPINS | 1960.1-2000.12 | DS | Consumer Price Index (NSA) |
| CAPPINS | 1960.1-2000.12 | DS | Industrial Price Index: All Commodities (NSA) |
| CATOTSA | 1971.1-2000.12 | DS | Terms Of Trade (Export Prices/Import Prices) (SA) |
| | | | **France** |
| FRIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| FRLIND | 1962.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| FRRSALE | 1963.1-2000.12 | OECD | Retail Sales: Major Outlets (volume index, 1995=100, SA) |
| FRNCARR | 1960.1-2000.12 | OECD | New Motor Vehicle Registrations (Thousands, SA) |
| FRUNEMP | 1978.1-2000.12 | OECD | Unemployment Rate (% of Total Labour Force, SA) |
| FRULCOS | 1960.1-2000.10 | OECD | Unit Labour Costs: Engineering Industries (1995=100, NSA) |
| FRIMPOR | 1970.1-2000.12 | OECD | Imports: Total (MIL FF, SA) |
| FREXPOR | 1970.1-2000.12 | OECD | Exports: Total (MIL FF, SA) |
| FRNMONS | 1960.1-1998.12 | OECD | Money Supply: M1 (MIL FF, SA) |
| FRBMONS | 1960.1-1998.12 | OECD | Money Supply: M3 (MIL FF, SA) |
| FRSIRAT | 1964.1-2000.12 | DS | Call Money Rate |
| FRLIRAT | 1960.1-2000.12 | DS | Government Guaranteed Bond Yield (EP) |
| FRSTOCK | 1960.1-2000.12 | OECD | Stock Index: SBF 250 |
| FREXRAT | 1974.1-1998.12 | DS | French Franc To US$ |
| FRCPINS | 1960.1-2000.12 | OECD | Consumer Price Index: All Items Excl. Food (1995=100, NSA) |
| FRPPINS | 1960.1-2000.12 | DS | Producer Price Index: Intermediate Goods (1990=100, NSA) |

| Series Name | Sample Period | Source | Description |
|---|---|---|---|
| | | | **Germany** |
| DEIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| DELIND | 1960.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| DERSALE | 1960.1-2000.12 | OECD | Retail Sales (volume index, 1995=100, SA) |
| DEORDER | 1962.1-2000.12 | DS | New Orders: Manufacturing (volume index, 1995=100, SA) |
| DENCARR | 1960.1-2000.5 | OECD | New Passenger Car Registrations (Thousands, SA) |
| DEUNEMP | 1962.1-2000.12 | OECD | Unemployment Rate (% of Civil Labour Force, SA) |
| DEULCOS | 1962.1-2000.12 | OECD | Unit Labour Costs: Mining & Manufacturing (1995=100, SA) |
| DEIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL DM, SA) |
| DEEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL DM, SA) |
| DENMONS | 1960.1-1998.12 | DS | Money Supply: M1 (MIL DM, SA) |
| DEBMONS | 1960.1-1998.12 | DS | Money Supply: M2 (MIL DM, SA) |
| DESIRAT | 1960.1-2000.12 | DS | 3-Month FIBOR |
| DELIRAT | 1960.1-2000.12 | DS | Long Term Government Bond Yield (9-10 Years Maturity) |
| DESTOCK | 1960.1-2000.12 | OECD | Stock Index: DAX (1995=100) |
| DEEXRAT | 1974.1-1998.12 | DS | German DMark To US$ |
| DECPINS | 1960.1-2000.12 | OECD | Consumer Price Index: All Items (1995=100, NSA) |
| DEPPINS | 1960.1-2000.12 | DS | Producer Price Index: Industrial Products (1995=100, NSA) |
| DETOTNS | 1960.1-2000.12 | DS | Terms Of Trade Index (1995=100, NSA) |
| | | | **Italy** |
| ITIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| ITLIND | 1966.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| ITRSALE | 1970.1-2000.12 | OECD | Retail Sales: Major Outlets (SA) |
| ITORDER | 1973.1-2000.12 | DS | New Orders: Manufacturing (NSA) |
| ITNCARR | 1960.1-2000.12 | OECD | New Passenger Car Registrations (Thousands, SA) |
| ITWAGES | 1960.1-2000.12 | OECD | Wage Earnings: Hourly, Manufacturing (1995=100, NSA) |
| ITIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL IL, SA) |
| ITEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL IL, SA) |
| ITNMONS | 1974.1-1998.12 | OECD | Money Supply: M1 (MIL IL, SA) |
| ITBMONS | 1975.1-1998.12 | OECD | Money Supply: M2 (MIL IL, SA) |
| ITSIRAT | 1971.1-2000.12 | DS | Interbank Deposit Rate (Average On 3-Months Deposits) |
| ITLIRAT | 1960.1-2000.12 | DS | Treasury Bond Net Yield: Secondary Market (EP) |
| ITSTOCK | 1960.1-2001.12 | OECD | Stock Index: ISE MIB STORICO |
| ITEXRAT | 1974.1-1998.12 | DS | Italian Lira To US$ |
| ITCPINS | 1960.1-2000.12 | OECD | Consumer Price Index: All Items (1995=100, NSA) |
| ITPPINS | 1981.1-2000.12 | OECD | Producer Price Index: Industrial Products (1995=100, NSA) |
| ITTOTNS | 1973.1-2000.11 | DS | Terms Of Trade (NSA) |
| | | | **Japan** |
| JPIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| JPLIND | 1960.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| JPRSALE | 1960.1-2000.12 | OECD | Retail Sales (volume index, 1995=100, SA) |
| JPORDER | 1960.1-2000.12 | OECD | New Orders: Manufacturing, Machinery (MIL ¥, SA) |
| JPNCARR | 1968.4-2000.12 | OECD | New Passenger Car Registrations (Thousands, SA) |
| JPUNEMP | 1960.1-2000.12 | OECD | Unemployment Rate (% of Total Labour Force, SA) |
| JPWAGES | 1960.1-2000.12 | DS | Wage Index: Contractors Cash Earnings, Manufacturing (¥, SA) |
| JPULCOS | 1960.1-2000.12 | OECD | Unit Labour Costs: Manufacturing Industry (1995=100, SA) |
| JPIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL ¥, SA) |
| JPEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL ¥, SA) |
| JPNMONS | 1960.1-2000.12 | OECD | Money Supply: M1 (MIL ¥, SA) |
| JPBMONS | 1960.1-2000.12 | OECD | Money Supply: M2+ (MIL ¥, SA) |
| JPSIRAT | 1960.1-2000.12 | DS | Overnight Uncollaterised Call Money Rate |
| JPLIRAT | 1966.10-2000.12 | DS | Interest-Bearing Government Bonds: 10-Year (EP) |
| JPSTOCK | 1960.1-2000.12 | DS | Stock Index: TOPIX (EP) |
| JPEXRAT | 1974.1-2000.12 | DS | Japanese Yen To US$ |
| JPCPINS | 1960.1-2000.12 | DS | Consumer Price Index: National Measure (1995=100, NSA) |
| JPPPINS | 1960.1-2000.12 | DS | Wholesale Price Index: Manufacturing Products (1995=100, NSA) |
| JPTOTNS | 1960.1-2000.12 | DS | Terms Of Trade Index (1995=100, NSA) |

| Series Name | Sample Period | Source | Description |
|---|---|---|---|
| | | | **UK** |
| UKIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| UKLIND | 1961.1-2000.12 | OECD | Composite Leading Indicator (TR) |
| UKRSALE | 1960.1-2000.12 | DS | Retail Sales (volume index, 1995=100, SA) |
| UKORDER | 1960.1-2000.12 | OECD | New Orders: Manufacturing, Engineering (1995=100, SA) |
| UKNCARR | 1960.1-1998.12 | ONS | New Registrations Of Cars (Thousands, SA) |
| UKUNEMP | 1960.1-2000.12 | OECD | Unemployment Rate (% of Total Labour Force, SA) |
| UKWAGES | 1963.1-2000.12 | DS | Average Earnings Index: Whole Economy (SA) |
| UKULCOS | 1963.1-2000.12 | OECD | Unit Labour Costs: Manufacturing (1995=100, SA) |
| UKIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL £, SA) |
| UKEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL £, SA) |
| UKNMONS | 1969.6-2000.12 | ONS | M0 Wide Monetary Base (MIL £, SA) |
| UKBMONS | 1982.6-2000.12 | ONS | Money Stock M4 (MIL £, SA) |
| UKSIRAT | 1960.1-2000.12 | DS | Bank Bill Rate: Discount, 3-Month |
| UKLIRAT | 1960.1-2000.12 | ONS | Government Bonds Yield: 10-Year |
| UKSTOCK | 1963.1-2000.12 | OECD | Stock Index: FTSE Non-Financials |
| UKEXRAT | 1974.1-2000.12 | DS | US$ To £1 |
| UKCPINS | 1960.1-2000.12 | DS | Retail Price Index (1987=100, NSA) |
| UKPPINS | 1960.1-2000.12 | OCED | Producer Price Index: Manufacturing Output (1995=100, NSA) |
| UKTOTNS | 1970.1-2000.12 | DS | Terms Of Trade Index (1995=100, NSA) |
| | | | **US** |
| USIPSA | 1960.1-2000.12 | OECD | Industrial Production: Total Excl. Construction (1995=100, SA) |
| USLIND | 1960.1-2000.12 | DS | The Conference Board's Leading Indicators Index |
| USRSALE | 1960.1-2000.12 | FRED | Retail Sales (MIL US$, SA) |
| USORDER | 1960.1-2000.12 | OECD | New Orders: Manufacturing (MIL US$, SA) |
| USNCARR | 1960.1-2000.8 | OECD | New Passenger Car Registrations (SA) |
| USUNEMP | 1960.1-2000.12 | FRED | Unemployment Rate (SA) |
| USWAGES | 1960.1-2000.12 | OECD | Wage Earnings: Manufacturing, Hourly (1995=100, NSA) |
| USIMPOR | 1960.1-2000.12 | OECD | Imports: Total (MIL US$, SA) |
| USEXPOR | 1960.1-2000.12 | OECD | Exports: Total (MIL US$, SA) |
| USNMONS | 1960.1-2000.12 | FRED | Money Stock: M1 (BIL US$, SA) |
| USBMONS | 1960.1-2000.12 | FRED | Money Stock: M2 (BIL US$, SA) |
| USSIRAT | 1960.1-2000.12 | FRED | 3-month Treasury Bill Rate, Secondary Market (MAV) |
| USLIRAT | 1960.1-2000.12 | FRED | 10-Year Treasury Bond Rate, Constant Maturity (MAV) |
| USSTOCK | 1963.1-2000.12 | DS | Stock Index: Standard & Poor's 500 |
| USCPINS | 1960.1-2000.12 | FRED | Consumer Price Index, All Urban Consumers (1982-84=100, NSA) |
| USPPINS | 1960.1-2000.12 | FRED | Producer Price Index, All Commodities (1982=100, NSA) |
| USTOTNS | 1969.1-2000.12 | DS | Terms Of Trade Index (1975=100, NSA) |

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Table 1: Tests for structural change in conditional volatility - percent rejections and median percent change in standard deviation across all series and per country

| | L | | SC | | NL | | NL-SC | |
|---|---|---|---|---|---|---|---|---|
| | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ |
| Total (125) | 81.6 | −34.5 | 76.0 | −34.2 | 81.6 | −32.4 | 77.6 | −32.6 |
| Canada (19) | 73.7 | 2.8 | 84.2 | −23.7 | 73.7 | 4.4 | 84.2 | −23.5 |
| France (16) | 87.5 | −40.0 | 75.0 | −41.2 | 81.3 | −40.9 | 75.0 | −38.3 |
| Germany (18) | 72.2 | −24.9 | 55.6 | −29.0 | 72.2 | −22.2 | 61.1 | −25.4 |
| Italy (17) | 82.4 | −37.8 | 82.4 | −40.0 | 82.4 | −39.6 | 88.2 | −36.5 |
| Japan (19) | 78.9 | −40.9 | 68.4 | −39.2 | 78.9 | −38.9 | 68.4 | −38.6 |
| UK (19) | 94.7 | −38.1 | 84.2 | −40.5 | 94.7 | −38.5 | 78.9 | −39.0 |
| US (17) | 82.4 | −33.0 | 82.4 | −33.4 | 88.2 | −28.2 | 88.2 | −31.5 |

The table contains results for SupW tests for structural change in conditional volatility. Columns headed "%R" contain the percent rejections of the null hypothesis of constant conditional volatility at the 5% nominal significance level, where the procedure of Hansen (1997) is used to obtain approximate asymptotic $p$-values. Columns headed "$\Delta\sigma$" contain the median percent change in the conditional standard deviation for those series for which the SupW test statistic is significant. Numbers in parentheses following the country names denote the number of series tested. Columns headed "L" contain results obtained with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for expansion-recession nonlinearity and a single structural change during expansions in the conditional mean.

Table 2: Tests for structural change in conditional volatility - number of rejections and median percent change in standard deviation for types of series

| Group | L | | SC | | NL | | NL-SC | |
|---|---|---|---|---|---|---|---|---|
| | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ |
| Industrial Production (7) | 5 | −36.7 | 5 | −36.5 | 5 | −36.8 | 5 | −36.5 |
| Leading Indicator (7) | 6 | −31.7 | 6 | −29.5 | 6 | −28.6 | 4 | −32.6 |
| Retail Sales (7) | 7 | −43.8 | 7 | −43.2 | 7 | −42.8 | 6 | −42.9 |
| Orders (6) | 2 | −38.7 | 3 | −31.0 | 2 | −37.2 | 3 | −31.6 |
| New Car Registrations (7) | 6 | −31.7 | 5 | −31.7 | 6 | −29.3 | 5 | −24.6 |
| Unemployment (6) | 2 | 7.1 | 2 | 2.7 | 3 | 31.5 | 3 | 29.5 |
| Wages (5) | 5 | −55.5 | 5 | −54.1 | 5 | −53.4 | 5 | −54.2 |
| Unit Labour Cost (5) | 3 | −46.6 | 3 | −41.4 | 3 | −44.5 | 4 | −31.8 |
| Imports (7) | 6 | −38.9 | 5 | −38.6 | 6 | −38.9 | 5 | −39.0 |
| Exports (7) | 6 | −29.6 | 4 | −33.6 | 6 | −28.6 | 3 | −37.7 |
| Narrow Money (7) | 7 | 38.5 | 6 | 4.4 | 7 | 40.0 | 7 | 43.0 |
| Broad Money (7) | 6 | 10.0 | 7 | −24.8 | 5 | 44.6 | 7 | −24.9 |
| ST Interest Rate (7) | 7 | −54.4 | 7 | −53.7 | 7 | −54.5 | 7 | −55.8 |
| LT Interest Rate (7) | 7 | 158.8 | 7 | 129.5 | 7 | 129.2 | 7 | 146.6 |
| Stock Index (7) | 6 | 45.0 | 5 | 44.8 | 6 | 44.1 | 5 | 43.9 |
| Exchange rate (6) | 5 | 54.7 | 2 | −3.4 | 4 | 45.0 | 4 | 46.4 |
| Consumer Prices (7) | 6 | −39.6 | 7 | −39.7 | 6 | −37.4 | 7 | −35.5 |
| Producer Prices (7) | 4 | −41.1 | 4 | −38.2 | 5 | −37.8 | 5 | −32.6 |
| Terms of Trade (6) | 6 | −42.7 | 5 | −43.4 | 6 | −46.5 | 5 | −38.1 |
| Total (125) | 102 | −34.5 | 95 | −34.2 | 102 | −32.4 | 97 | −32.6 |

The table contains results for SupW tests for structural change in conditional volatility. Columns headed "#R" contain the number of rejections of the null hypothesis of constant conditional volatility at the 5% nominal significance level, where the procedure of Hansen (1997) is used to obtain approximate asymptotic $p$-values. Columns headed "$\Delta\sigma$" contain the median percent change in the conditional standard deviation for those series for which the SupW test statistic is significant. Numbers in parentheses following the series type denote the number of series tested. Columns headed "L" contain results obtained with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for expansion-recession nonlinearity and a single structural change during expansions in the conditional mean.

Table 3: Tests for structural change and nonlinearity in conditional mean - percent rejections over all series and per country

| | SC-L | NL | NL-SC |
|---|---|---|---|
| Total | 58.4 | 48.8 | 52.8 |
| Canada | 68.4 | 47.4 | 42.1 |
| France | 62.5 | 25.0 | 56.3 |
| Germany | 27.8 | 55.6 | 38.9 |
| Italy | 52.9 | 47.1 | 47.1 |
| Japan | 84.2 | 57.9 | 78.9 |
| UK | 57.9 | 31.6 | 52.6 |
| US | 52.9 | 76.5 | 52.9 |

The table contains percent rejections across all series and per country at the 5% nominal significance level. The column headed "SC-L" concerns results from SupW tests for a single structural change in the parameters in the linear autoregressive model (1). The column headed "NL" concerns results from Wald tests for differences in the AR parameters in business cycle expansions and recessions, defined using the ECRI-dated turning points. The column headed "NL-SC" concerns results from SupW tests for a single structural change in the parameters during expansions in the nonlinear autoregressive model (3). The procedure of Hansen (1997) is used to obtain approximate asymptotic $p$-values for the structural change tests.

Table 4: Tests for structural change and nonlinearity in conditional mean - percent rejections per type

| | SC-L | NL | NL-SC |
|---|---|---|---|
| Industrial Production | 4 | 7 | 3 |
| Leading Indicator | 3 | 4 | 4 |
| Retail Sales | 3 | 5 | 5 |
| Orders | 4 | 4 | 4 |
| New Car Registrations | 4 | 4 | 3 |
| Unemployment | 3 | 6 | 1 |
| Wages | 5 | 2 | 5 |
| Unit Labour Cost | 5 | 2 | 2 |
| Imports | 4 | 4 | 4 |
| Exports | 3 | 1 | 5 |
| Narrow Money | 4 | 1 | 5 |
| Broad Money | 4 | 0 | 4 |
| ST Interest Rate | 5 | 4 | 5 |
| LT Interest Rate | 3 | 2 | 2 |
| Stock Index | 1 | 0 | 1 |
| Exchange rate | 0 | 2 | 0 |
| Consumer Prices | 7 | 6 | 7 |
| Producer Prices | 6 | 4 | 3 |
| Terms of Trade | 4 | 3 | 3 |
| Total | 73 | 61 | 66 |

The table contains the number of rejections per type of series at the 5% nominal significance level. The column headed "SC-L" concerns results from SupW tests for a single structural change in the parameters in the linear autoregressive model (1). The column headed "NL" concerns results from Wald tests for differences in the AR parameters in business cycle expansions and recessions, defined using the ECRI-dated turning points. The column headed "NL-SC" concerns results from SupW tests for a single structural change in the parameters during expansions in the nonlinear autoregressive model (3). The procedure of Hansen (1997) is used to obtain approximate asymptotic $p$-values for the structural change tests.

Table 5: Tests for nonlinearity in conditional volatility - percent rejections and median percent difference in standard deviation in expansions and recessions across all series and per country

| | L | | SC | | NL | | NL-SC | |
|---|---|---|---|---|---|---|---|---|
| | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ |
| Total | 45.6 | 46.3 | 40.0 | 44.0 | 40.0 | 33.3 | 41.6 | 37.1 |
| Canada | 47.4 | 32.9 | 36.8 | 40.4 | 31.6 | −0.4 | 26.3 | 30.0 |
| France | 18.8 | 46.2 | 18.8 | 36.0 | 18.8 | 30.9 | 18.8 | 40.0 |
| Germany | 44.4 | 26.8 | 44.4 | 24.0 | 27.8 | 26.7 | 38.9 | 30.4 |
| Italy | 47.1 | 41.4 | 29.4 | 46.8 | 52.9 | 34.2 | 52.9 | 36.9 |
| Japan | 26.3 | 53.2 | 21.1 | 37.4 | 42.1 | 1.5 | 36.8 | 34.1 |
| UK | 47.4 | 48.8 | 47.4 | 40.4 | 42.1 | 37.1 | 42.1 | 41.9 |
| US | 88.2 | 53.8 | 82.4 | 57.7 | 64.7 | 54.1 | 76.5 | 51.5 |

The table contains results for Wald tests for nonlinearity in conditional volatility. Columns headed "%R" contain the percent rejections at the 5% nominal significance level. Columns headed "$\Delta\sigma$" contain the median percent difference between the conditional standard deviations in recessions and expansions (as a percentage of the latter) for those series for which the Wald statistic is significant. Columns headed "L" contain results obtained with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for expansion-recession nonlinearity and a single structural change during expansions in the conditional mean.

Table 6: Tests for nonlinearity in conditional volatility - number of rejections and median percent change in standard deviation for groups

| | L | | SC | | NL | | NL-SC | |
|---|---|---|---|---|---|---|---|---|
| Group | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ |
| Industrial Production | 2 | 60.3 | 3 | 28.8 | 2 | 29.2 | 2 | 32.7 |
| Leading Indicator | 4 | 30.7 | 4 | 32.1 | 2 | 48.6 | 2 | 52.2 |
| Retail Sales | 2 | 46.4 | 2 | 46.8 | 2 | 11.3 | 1 | 50.5 |
| Orders | 2 | 40.4 | 2 | 37.1 | 3 | −24.8 | 3 | −22.4 |
| New Car Registrations | 1 | 52.6 | 1 | 71.3 | 1 | 32.7 | 1 | 49.1 |
| Unemployment | 4 | 45.9 | 4 | 49.1 | 2 | 28.6 | 2 | 30.4 |
| Wages | 2 | 41.1 | 1 | 44.2 | 1 | 36.0 | 2 | 35.4 |
| Unit Labour Cost | 3 | 52.7 | 2 | 48.0 | 2 | 53.0 | 2 | 57.5 |
| Imports | 4 | 54.8 | 4 | 50.3 | 4 | 41.7 | 4 | 48.8 |
| Exports | 2 | 30.0 | 2 | 31.0 | 1 | 34.2 | 2 | 28.0 |
| Narrow Money | 2 | 10.7 | 1 | 40.4 | 2 | −3.5 | 2 | −0.7 |
| Broad Money | 1 | 28.7 | 2 | −8.7 | 2 | −41.7 | 1 | −56.7 |
| ST Interest Rate | 4 | 58.5 | 4 | 60.9 | 4 | 60.6 | 4 | 62.6 |
| LT Interest Rate | 6 | 62.9 | 6 | 55.5 | 6 | 60.6 | 6 | 61.0 |
| Stock Index | 5 | 33.9 | 4 | 38.6 | 4 | 38.3 | 4 | 41.0 |
| Exchange rate | 1 | 23.4 | 0 | – | 0 | – | 1 | 21.5 |
| Consumer Prices | 5 | 38.3 | 3 | 43.8 | 4 | 30.5 | 5 | 37.4 |
| Producer Prices | 4 | 47.9 | 3 | 38.3 | 5 | 24.5 | 5 | 33.3 |
| Terms of Trade | 3 | 38.4 | 2 | 0.9 | 3 | 33.9 | 3 | 35.6 |
| Total | 57 | 46.3 | 50 | 44.0 | 50 | 33.3 | 52 | 37.1 |

The table contains results for Wald tests for nonlinearity in conditional volatility. Columns headed "#R" contain the number of rejections at the 5% nominal significance level. Columns headed "$\Delta\sigma$" contain the median percent difference between the conditional standard deviations in recessions and expansions (as a percentage of the latter) for those series for which the Wald statistic is significant. Columns headed "L" contain results obtained with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for expansion-recession nonlinearity and a single structural change during expansions in the conditional mean.

Table 7: Tests for structural change in conditional volatility during recessions and expansions - percent rejections and median percent change in standard deviation across all series and per country

| | L | | | | SC | | | | NL | | | | NL-SC | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\%R_E$ | $\Delta\sigma_E$ | $\%R_R$ | $\Delta\sigma_R$ | $\%R_E$ | $\Delta\sigma_E$ | $\%R_R$ | $\Delta\sigma_R$ | $\%R_E$ | $\Delta\sigma_E$ | $\%R_R$ | $\Delta\sigma_R$ | $\%R_E$ | $\Delta\sigma_E$ | $\%R_R$ | $\Delta\sigma_R$ |
| Total | 72.0 | −34.3 | 51.2 | −53.8 | 73.6 | −33.7 | 56.0 | −54.7 | 74.4 | −32.5 | 38.4 | −54.5 | 72.8 | −33.4 | 43.2 | −54.0 |
| Canada | 63.2 | −30.6 | 47.4 | −63.0 | 68.4 | −27.2 | 52.6 | −57.9 | 63.2 | −29.7 | 42.1 | −56.9 | 73.7 | −24.9 | 42.1 | −58.9 |
| France | 75.0 | −41.9 | 62.5 | −54.5 | 75.0 | −40.8 | 62.5 | −55.2 | 81.3 | −40.0 | 31.3 | −56.8 | 68.8 | −39.9 | 37.5 | −52.5 |
| Germany | 61.1 | −24.5 | 38.9 | −45.2 | 66.7 | −25.4 | 50.0 | −45.3 | 66.7 | −24.2 | 33.3 | −45.5 | 72.2 | −22.6 | 33.3 | −45.5 |
| Italy | 76.5 | −42.4 | 58.8 | −50.3 | 82.4 | −38.2 | 58.8 | −47.0 | 76.5 | −43.1 | 35.3 | −48.3 | 82.4 | −36.9 | 52.9 | −50.8 |
| Japan | 73.7 | −35.7 | 52.6 | −84.1 | 68.4 | −39.9 | 52.6 | −82.8 | 73.7 | −34.9 | 42.1 | −79.5 | 63.2 | −39.7 | 42.1 | −79.5 |
| UK | 89.5 | −41.6 | 47.4 | −62.1 | 73.7 | −39.7 | 47.4 | −60.4 | 89.5 | −42.3 | 42.1 | −52.9 | 73.7 | −39.6 | 42.1 | −52.9 |
| US | 64.7 | −29.9 | 52.9 | 118.4 | 82.4 | −27.5 | 70.6 | 74.1 | 70.6 | −29.4 | 41.2 | −57.5 | 76.5 | −27.4 | 52.9 | −53.9 |

The table contains results for SupW tests for structural change in conditional volatility during recessions and expansions separately, while allowing these to be different under the null hypothesis. Columns headed "$\%R_E$" ("$\%R_R$") contain percent rejections at the 5% nominal significance level of the null hypothesis of constant conditional volatility during expansions (recessions), where the procedure of Hansen (1997) is used to obtain approximate asymptotic $p$-values. Columns headed "$\Delta\sigma_E$" ("$\Delta\sigma_R$") contain the median percent change in the conditional standard deviation in expansions (recessions) for those series for which the SupW test statistic is significant. Columns headed "L" contain results with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for different autoregressive parameters in expansions and recessions and for a single structural change in the parameters during expansions.

Table 8: Tests for structural change in conditional volatility during recessions and expansions - number of rejections and median percentage change in standard deviation for groups of series

| | L | | | | SC | | | | NL | | | | NL-SC | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\#R_E$ | $\Delta\sigma_E$ | $\#R_R$ | $\Delta\sigma_R$ | $\#R_E$ | $\Delta\sigma_E$ | $\#R_R$ | $\Delta\sigma_R$ | $\#R_E$ | $\Delta\sigma_E$ | $\#R_R$ | $\Delta\sigma_R$ | $\#R_E$ | $\Delta\sigma_E$ | $\#R_R$ | $\Delta\sigma_R$ |
| Industrial Production | 6 | −34.9 | 3 | −51.8 | 6 | −33.4 | 4 | −49.2 | 6 | −33.0 | 3 | −57.5 | 6 | −34.3 | 3 | −57.5 |
| Leading Indicator | 5 | −31.7 | 6 | −46.6 | 6 | −26.9 | 6 | −40.0 | 5 | −31.6 | 3 | −35.5 | 4 | −29.9 | 3 | −35.5 |
| Retail Sales | 7 | −41.6 | 2 | 34.8 | 7 | −41.7 | 2 | 44.2 | 7 | −43.3 | 1 | −71.6 | 6 | −42.1 | 2 | 18.8 |
| Orders | 2 | −38.5 | 2 | −61.2 | 3 | −31.6 | 2 | −59.0 | 2 | −37.0 | 2 | 24.8 | 3 | −31.8 | 2 | 24.8 |
| New Car Registrations | 6 | −33.6 | 3 | −60.0 | 4 | −34.2 | 4 | −50.0 | 5 | −32.9 | 1 | −79.1 | 4 | −33.1 | 1 | −79.1 |
| Unemployment | 1 | 44.2 | 2 | −46.2 | 1 | −26.3 | 2 | −43.1 | 1 | 39.8 | 2 | −57.9 | 2 | 6.5 | 2 | −57.9 |
| Wages | 5 | −52.8 | 4 | −67.7 | 5 | −53.2 | 5 | −67.0 | 5 | −53.4 | 3 | −68.1 | 4 | −56.5 | 4 | −66.7 |
| Unit Labour Cost | 2 | −46.8 | 3 | −62.5 | 3 | −39.2 | 4 | −55.7 | 2 | −47.8 | 2 | −47.6 | 3 | −38.6 | 3 | −48.2 |
| Imports | 6 | −42.8 | 3 | −50.5 | 6 | −38.6 | 3 | −46.3 | 6 | −40.0 | 2 | 36.0 | 6 | −37.4 | 2 | 36.0 |
| Exports | 6 | −30.2 | 1 | −50.0 | 3 | −39.3 | 1 | −50.1 | 6 | −29.9 | 1 | −54.1 | 4 | −32.5 | 1 | −54.1 |
| Narrow Money | 6 | 59.3 | 4 | −55.4 | 7 | 57.3 | 4 | −52.0 | 7 | 57.8 | 4 | −55.2 | 7 | 52.7 | 4 | −55.2 |
| Broad Money | 4 | 3.0 | 2 | −55.4 | 6 | 9.1 | 3 | −55.7 | 5 | 42.1 | 1 | −61.0 | 6 | 8.0 | 2 | −57.5 |
| ST Interest Rate | 7 | −54.2 | 6 | 29.8 | 7 | −54.3 | 6 | −63.8 | 7 | −54.1 | 6 | −59.7 | 7 | −55.9 | 6 | −59.7 |
| LT Interest Rate | 7 | 153.9 | 5 | −44.6 | 7 | 160.0 | 5 | −40.3 | 7 | 151.0 | 5 | −44.9 | 7 | 151.8 | 5 | −44.9 |
| Stock Index | 5 | 49.3 | 3 | −56.2 | 4 | 48.6 | 3 | −57.1 | 5 | 46.0 | 3 | −68.3 | 5 | 44.2 | 3 | −68.3 |
| Exchange rate | 1 | 17.4 | 1 | 76.1 | 1 | −37.4 | 1 | 98.1 | 2 | 20.5 | 1 | 89.6 | 3 | 35.5 | 1 | 89.6 |
| Consumer Prices | 6 | −39.5 | 6 | −57.0 | 7 | −35.4 | 7 | −54.8 | 6 | −38.0 | 2 | −66.5 | 6 | −37.4 | 3 | −52.5 |
| Producer Prices | 3 | −44.4 | 4 | −59.6 | 4 | −39.0 | 4 | −63.6 | 3 | −42.3 | 3 | −50.8 | 3 | −41.0 | 3 | −50.8 |
| Terms of Trade | 5 | −46.1 | 4 | −53.0 | 5 | −41.3 | 3 | −56.4 | 6 | −45.4 | 3 | −54.9 | 5 | −38.3 | 4 | −56.2 |
| Total | 90 | −34.3 | 64 | −53.8 | 92 | −33.7 | 70 | −54.7 | 93 | −32.5 | 48 | −54.5 | 91 | −33.4 | 54 | −54.0 |

The table contains results for SupW tests for structural change in conditional volatility during recessions and expansions separately, while allowing these to be different under the null hypothesis. Columns headed "$\#R_E$" ("$\#R_R$") contain the number of rejections at the 5% nominal significance level of the null hypothesis of constant conditional volatility during expansions (recessions), where the procedure of Hansen (1997) is used to obtain approximate asymptotic *p*-values. Columns headed "$\Delta\sigma_E$" ("$\Delta\sigma_R$") contain the median percent change in the conditional standard deviation in expansions (recessions) for those series for which the SupW test statistic is significant. Columns headed "L" contain results with a linear and time-invariant AR model for the conditional mean. Columns headed "SC" contain results obtained when allowing for a single structural change in the model for the conditional mean. Columns headed "NL" contain results obtained when allowing for different autoregressive parameters in expansions and recessions. Columns headed "NL-SC" contain results obtained when allowing for different autoregressive parameters in expansions and recessions and for a single structural change in the parameters during expansions.

Table 9: Tests for multiple structural changes in conditional volatility - nonlinear model with structural change during expansions for conditional mean

| | 1 change | | 2 changes | | 3 changes | | Overall | | Before 1980 | | After 1980 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %R | $\Delta\sigma$ | %B | $\Delta\sigma$ | %B | $\Delta\sigma$ |
| Total | 44.8 | −32.5 | 25.6 | −6.7 | 7.2 | −10.4 | 77.6 | −24.9 | 41.5 | 63.0 | 58.5 | −38.5 |
| Canada | 63.2 | −26.3 | 5.3 | −44.8 | 15.8 | 44.5 | 84.2 | −23.5 | 77.8 | −0.4 | 22.2 | 6.6 |
| France | 62.5 | −38.3 | 12.5 | 123.1 | 0.0 | – | 75.0 | −24.4 | 26.1 | 86.2 | 73.9 | −30.0 |
| Germany | 22.2 | 42.1 | 38.9 | 9.9 | 0.0 | – | 61.1 | 2.6 | 35.7 | −35.1 | 64.3 | −38.5 |
| Italy | 58.8 | −28.1 | 29.4 | −27.4 | 0.0 | – | 88.2 | −25.3 | 45.0 | 70.2 | 55.0 | −40.7 |
| Japan | 42.1 | −39.4 | 15.8 | 29.1 | 10.5 | −68.3 | 68.4 | −27.4 | 40.0 | −32.5 | 60.0 | −39.9 |
| UK | 26.3 | −37.9 | 36.8 | −24.3 | 15.8 | −19.1 | 78.9 | −25.4 | 28.6 | 80.5 | 71.4 | −40.0 |
| US | 41.2 | −34.7 | 41.2 | 15.4 | 5.9 | 61.4 | 88.2 | −24.9 | 45.8 | 73.1 | 54.2 | −35.1 |

The table contains results for sequential tests for multiple structural changes in conditional volatility, when using a nonlinear AR($p$) model with a single structural change during expansions for the conditional mean. In the blocks headed "$m$ change(s)", $m = 1, 2, 3$, columns headed "%R" contain the percent of series for which $m$ changes in variability are found based upon the SupW test, while columns headed "$\Delta\sigma$" 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 - $\Delta\sigma$" contain the median percent "net" change in the standard deviation across all series for which at least one change is found. In the blocks headed "Before (After) 1980", columns headed "%B" contain the percent of breaks which is dated before (after) January 1980, while columns headed "$\Delta\sigma$" contain the median percent change in the standard deviation across these breaks.

Table 10: Tests for multiple structural changes in conditional volatility - nonlinear model with structural change during expansions for conditional mean

| | 1 change | | 2 changes | | 3 changes | | Overall | | Before 1980 | | After 1980 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #R | $\Delta\sigma$ | #B | $\Delta\sigma$ | #B | $\Delta\sigma$ |
| Industrial Production | 4 | −36.5 | 1 | −4.3 | 0 | – | 5 | −35.1 | 1 | 70.2 | 5 | −37.9 |
| Leading Indicator | 3 | −30.4 | 1 | −19.5 | 0 | – | 4 | −30.4 | 3 | −30.4 | 2 | −36.2 |
| Retail Sales | 6 | −42.9 | 0 | – | 0 | – | 6 | −35.1 | 1 | −35.1 | 5 | −43.4 |
| Orders | 2 | −29.8 | 1 | −19.9 | 0 | – | 3 | −34.4 | 2 | 0.2 | 2 | −29.8 |
| New Car Registrations | 2 | −23.0 | 3 | −44.8 | 0 | – | 5 | −34.1 | 3 | −21.2 | 5 | −29.4 |
| Unemployment | 2 | 32.4 | 1 | −11.2 | 0 | – | 3 | −32.1 | 3 | 35.3 | 1 | −38.0 |
| Wages | 3 | −24.3 | 1 | −68.0 | 1 | −63.0 | 5 | −33.8 | 2 | −51.0 | 6 | −33.7 |
| Unit Labour Costs | 3 | −22.1 | 1 | 13.9 | 0 | – | 4 | −30.4 | 1 | 80.6 | 4 | −29.5 |
| Imports | 2 | −33.7 | 3 | −31.6 | 0 | – | 5 | −32.1 | 3 | 56.5 | 5 | −46.5 |
| Exports | 2 | −32.6 | 1 | −27.4 | 0 | – | 3 | −31.6 | 1 | 70.3 | 3 | −37.7 |
| Narrow Money | 5 | −38.1 | 2 | 27.0 | 0 | – | 7 | −31.0 | 4 | 24.3 | 5 | −31.1 |
| Broad Money | 5 | −24.9 | 2 | 14.5 | 0 | – | 7 | −28.1 | 5 | −40.4 | 4 | 20.3 |
| ST Interest Rate | 1 | −55.8 | 2 | −75.5 | 4 | −26.8 | 7 | −31.0 | 7 | 78.0 | 10 | −52.6 |
| LT Interest Rate | 3 | 146.6 | 2 | 277.8 | 2 | 89.2 | 7 | −27.4 | 9 | 137.4 | 4 | −39.3 |
| Stock Index | 2 | 46.2 | 3 | 15.2 | 0 | – | 5 | −25.0 | 5 | 45.3 | 3 | 76.9 |
| Exchange Rate | 2 | 46.7 | 2 | −16.7 | 0 | – | 4 | −24.5 | 0 | – | 6 | 43.1 |
| Consumer Prices | 5 | −31.5 | 1 | −29.4 | 1 | −19.1 | 7 | −25.2 | 3 | 78.0 | 7 | −37.0 |
| Producer Prices | 1 | −55.2 | 3 | 15.4 | 1 | 44.5 | 5 | −24.8 | 6 | 73.8 | 4 | −51.8 |
| Terms of Trade | 3 | −52.7 | 2 | 19.5 | 0 | – | 5 | −24.9 | 2 | 107.2 | 5 | −43.0 |
| Total | 56 | −32.5 | 32 | −6.7 | 9 | −10.4 | 97 | −24.9 | 61 | 63.0 | 86 | −38.1 |

The table contains results for sequential tests for multiple structural changes in conditional volatility, when using a nonlinear AR($p$) model with a single structural change during expansions for the conditional mean. In the blocks headed "$m$ change(s)", $m = 1, 2, 3$, columns headed "#R" contain the number of series for which $m$ changes in variability are found based upon the SupW test, while columns headed "$\Delta\sigma$" 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 - $\Delta\sigma$" contain the median percent "net" change in the standard deviation across all series for which at least one change is found. In the blocks headed "Before (After) 1980", columns headed "#B" contain the number of breaks which is dated before (after) January 1980, while columns headed "$\Delta\sigma$" contain the median percent change in the standard deviation across these breaks.

Table A.1: Tests for structural change in conditional volatility - results for individual series

| Series | $p$ | $\sigma_0$ | $\sigma_1$ | $\sigma_2$ | $\Delta\sigma$ | $\tau_v$ | p-value |
|---|---|---|---|---|---|---|---|
| **Canada** | | | | | | | |
| CAIPSA | 5 | 12.42 | 14.26 | 9.82 | −31.17 | 1984.10 | 5.34E-005 |
| | | [0.47] | [0.60] | [0.71] | [5.75] | [1982.10,1988.12] | |
| CALIND | 10 | 4.76 | 4.96 | 4.49 | −9.51 | 1983.05 | 0.899 |
| | | [0.19] | [0.25] | [0.28] | [7.36] | [1961.02,2000.12] | |
| CARSALE | 12 | 17.38 | 21.74 | 12.05 | −44.56 | 1983.06 | 2.47E-012 |
| | | [0.68] | [0.86] | [0.95] | [4.90] | [1982.11,1985.07] | |
| CAORDER | 2 | 30.46 | 25.35 | 31.51 | 24.30 | 1967.11 | 0.274 |
| | | [1.07] | [2.57] | [1.17] | [13.42] | [1961.02,1972.10] | |
| CANCARR | 6 | 77.93 | 90.01 | 59.70 | −33.68 | 1985.01 | 6.80E-006 |
| | | [2.93] | [3.67] | [4.51] | [5.69] | [1983.10,1988.12] | |
| CAUNEMP | 5 | 252.66 | 260.11 | 213.81 | −17.80 | 1994.07 | 0.558 |
| | | [9.88] | [10.75] | [24.57] | [10.04] | [1986.05,2000.12] | |
| CAWAGES | 12 | 7.30 | 6.57 | 11.07 | 68.49 | 1994.06 | 3.92E-007 |
| | | [0.30] | [0.32] | [0.72] | [13.60] | [1991.11,1995.05] | |
| CAULCOS | 6 | 13.48 | 14.72 | 12.08 | −17.99 | 1982.09 | 0.101 |
| | | [0.50] | [0.68] | [0.73] | [6.23] | [1976.01,1996.12] | |
| CAIMPOR | 3 | 42.18 | 47.20 | 28.71 | −39.17 | 1990.02 | 0.000113 |
| | | [1.82] | [2.08] | [3.41] | [7.71] | [1989.02,1993.12] | |
| CAEXPOR | 12 | 43.65 | 51.02 | 34.53 | −32.31 | 1983.02 | 5.51E-005 |
| | | [1.75] | [2.30] | [2.56] | [5.88] | [1981.05,1987.11] | |
| CANMONS | 12 | 14.07 | 10.78 | 16.68 | 54.80 | 1978.09 | 1.78E-005 |
| | | [0.60] | [0.88] | [0.78] | [14.56] | [1974.04,1980.03] | |
| CABMONS | 6 | 4.90 | 5.60 | 4.39 | −21.73 | 1982.08 | 0.0860 |
| | | [0.22] | [0.34] | [0.29] | [7.04] | [1977.09,1994.12] | |
| CASIRAT | 10 | 486.43 | 329.61 | 624.18 | 89.37 | 1979.09 | 2.17E-006 |
| | | [27.88] | [39.58] | [37.09] | [25.37] | [1974.12,1980.02] | |
| CALIRAT | 12 | 345.50 | 186.58 | 482.78 | 158.76 | 1979.07 | 9.49E-019 |
| | | [17.25] | [23.33] | [21.68] | [34.37] | [1977.10,1979.09] | |
| CASTOCK | 2 | 50.93 | 36.03 | 53.91 | 49.63 | 1967.09 | 0.0256 |
| | | [2.12] | [5.15] | [2.30] | [22.30] | [1962.05,1968.12] | |
| CAEXRAT | 10 | 12.30 | 11.62 | 15.77 | 35.69 | 1996.09 | 0.0425 |
| | | [0.52] | [0.56] | [1.27] | [12.72] | [1992.12,1999.08] | |
| CACPINS | 12 | 3.53 | 4.03 | 2.82 | −30.00 | 1984.05 | 0.000350 |
| | | [0.14] | [0.18] | [0.21] | [6.10] | [1980.05,1988.04] | |
| CAPPINS | 11 | 5.04 | 4.67 | 6.87 | 46.97 | 1994.05 | 0.00150 |
| | | [0.21] | [0.22] | [0.50] | [12.79] | [1990.12,1996.10] | |
| CATOTSA | 9 | 15.25 | 27.88 | 9.84 | −64.71 | 1980.09 | 9.81E-030 |
| | | [0.83] | [1.29] | [0.84] | [3.44] | [1980.07,1981.08] | |
| **France** | | | | | | | |
| FRIPSA | 6 | 13.65 | 15.55 | 8.98 | −42.28 | 1989.05 | 5.46E-007 |
| | | [0.54] | [0.62] | [0.98] | [6.68] | [1988.09,1992.02] | |
| FRLIND | 11 | 4.11 | 4.74 | 3.51 | −25.94 | 1981.05 | 0.00626 |
| | | [0.17] | [0.24] | [0.24] | [6.28] | [1977.07,1988.12] | |
| FRRSALE | 12 | 22.44 | 30.03 | 18.89 | −37.09 | 1975.10 | 2.26E-006 |
| | | [0.99] | [1.70] | [1.16] | [5.24] | [1974.12,1980.07] | |
| FRNCARR | 12 | 67.83 | 79.32 | 56.77 | −28.43 | 1980.08 | 0.00144 |
| | | [2.85] | [4.00] | [3.93] | [6.13] | [1976.10,1986.06] | |
| FRUNEMP | 10 | 94.05 | 105.78 | 89.45 | −15.44 | 1985.03 | 0.616 |
| | | [4.48] | [8.41] | [5.26] | [8.36] | [1979.02,2000.12] | |
| FRULCOS | 12 | 6.78 | 8.96 | 4.01 | −55.22 | 1983.04 | 5.33E-015 |
| | | [0.32] | [0.39] | [0.44] | [5.34] | [1982.11,1985.02] | |
| FRIMPOR | 12 | 33.41 | 42.67 | 26.21 | −38.59 | 1984.02 | 5.25E-007 |
| | | [1.50] | [2.17] | [1.91] | [5.47] | [1982.12,1986.09] | |
| FREXPOR | 9 | 35.01 | 37.49 | 30.00 | −19.96 | 1991.01 | 0.195 |
| | | [1.51] | [1.83] | [2.60] | [7.95] | [1982.12,2000.12] | |
| FRNMONS | 12 | 8.13 | 11.63 | 6.81 | −41.47 | 1978.08 | 1.47E-006 |
| | | [0.41] | [0.75] | [0.46] | [5.45] | [1977.07,1980.12] | |
| FRBMONS | 12 | 4.87 | 8.79 | 4.04 | −53.97 | 1975.10 | 1.56E-014 |
| | | [0.24] | [0.53] | [0.24] | [3.89] | [1975.06,1977.02] | |
| FRSIRAT | 4 | 484.62 | 685.36 | 359.27 | −47.58 | 1982.07 | 4.02E-006 |
| | | [31.01] | [48.15] | [38.05] | [6.66] | [1981.04,1985.09] | |
| FRLIRAT | 3 | 251.30 | 120.20 | 363.59 | 202.48 | 1979.06 | 1.63E-015 |
| | | [15.37] | [21.10] | [19.53] | [55.52] | [1977.06,1979.08] | |
| FRSTOCK | 10 | 61.40 | 65.97 | 48.02 | −27.21 | 1990.10 | 0.0228 |
| | | [2.46] | [2.82] | [4.83] | [7.95] | [1988.06,1998.01] | |
| FREXRAT | 3 | 28.61 | 20.00 | 30.94 | 54.70 | 1980.02 | 0.0197 |
| | | [1.40] | [2.98] | [1.55] | [24.30] | [1976.07,1981.07] | |
| FRCPINS | 12 | 3.50 | 4.34 | 2.48 | −42.82 | 1982.12 | 5.19E-011 |
| | | [0.14] | [0.17] | [0.19] | [5.01] | [1982.01,1985.02] | |
| FRPPINS | 12 | 6.16 | 8.25 | 3.57 | −56.69 | 1983.02 | 3.15E-012 |
| | | [0.33] | [0.42] | [0.46] | [6.02] | [1982.11,1985.07] | |

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| Series | $p$ | $\sigma_0$ | $\sigma_1$ | $\sigma_2$ | $\Delta\sigma$ | $\tau_v$ | p-value |
|---|---|---|---|---|---|---|---|
| **Germany** | | | | | | | |
| DEIPSA | 6 | 16.71 | 17.43 | 13.23 | −24.06 | 1994.02 | 0.135 |
| | | [0.63] | [0.69] | [1.51] | [9.17] | [1990.11,2000.12] | |
| DELIND | 12 | 4.00 | 4.64 | 3.51 | −24.40 | 1978.05 | 0.00468 |
| | | [0.15] | [0.23] | [0.20] | [5.74] | [1974.07,1986.02] | |
| DERSALE | 11 | 21.11 | 22.29 | 15.70 | −29.57 | 1993.10 | 0.0178 |
| | | [0.78] | [0.85] | [1.81] | [8.56] | [1992.03,1998.11] | |
| DEORDER | 5 | 28.79 | 36.61 | 23.62 | −35.50 | 1978.02 | 4.14E-007 |
| | | [1.15] | [1.76] | [1.43] | [4.99] | [1976.09,1981.05] | |
| DENCARR | 6 | 68.55 | 73.30 | 53.29 | −27.30 | 1991.01 | 0.0303 |
| | | [2.76] | [3.13] | [5.61] | [8.26] | [1987.01,1997.06] | |
| DEUNEMP | 4 | 91.80 | 75.28 | 98.92 | 31.41 | 1974.06 | 0.0556 |
| | | [3.78] | [6.83] | [4.48] | [13.33] | [1967.01,1981.12] | |
| DEULCOS | 9 | 18.94 | 20.19 | 17.28 | −14.40 | 1984.08 | 0.428 |
| | | [0.75] | [1.00] | [1.15] | [7.07] | [1970.02,2000.12] | |
| DEIMPOR | 6 | 40.24 | 44.17 | 38.06 | −13.83 | 1975.04 | 0.440 |
| | | [1.55] | [2.58] | [1.92] | [6.66] | [1961.02,1999.12] | |
| DEEXPOR | 3 | 39.53 | 49.22 | 36.98 | −24.86 | 1969.05 | 0.0146 |
| | | [1.50] | [3.24] | [1.67] | [6.00] | [1965.09,1976.04] | |
| DENMONS | 3 | 9.24 | 7.19 | 9.95 | 38.47 | 1970.10 | 0.0400 |
| | | [0.40] | [0.79] | [0.46] | [16.54] | [1963.02,1973.11] | |
| DEBMONS | 10 | 7.87 | 9.12 | 6.97 | −23.55 | 1976.12 | 0.0280 |
| | | [0.34] | [0.52] | [0.44] | [6.53] | [1972.06,1987.10] | |
| DESIRAT | 6 | 364.39 | 590.93 | 246.31 | −58.32 | 1981.04 | 3.68E-012 |
| | | [23.45] | [37.26] | [26.90] | [5.26] | [1981.01,1983.08] | |
| DELIRAT | 3 | 220.01 | 109.11 | 249.27 | 128.46 | 1969.05 | 5.94E-010 |
| | | [8.79] | [18.37] | [9.44] | [39.43] | [1967.10,1969.08] | |
| DESTOCK | 1 | 42.54 | 36.89 | 51.60 | 39.89 | 1985.08 | 0.000919 |
| | | [1.76] | [2.21] | [2.79] | [11.29] | [1978.05,1987.12] | |
| DEEXRAT | 1 | 29.93 | 19.06 | 31.90 | 67.42 | 1978.09 | 0.0147 |
| | | [1.41] | [3.52] | [1.50] | [31.94] | [1976.02,1979.09] | |
| DECPINS | 12 | 2.74 | 3.38 | 2.63 | −22.40 | 1967.02 | 0.146 |
| | | [0.11] | [0.28] | [0.12] | [7.31] | [1961.02,1974.04] | |
| DEPPINS | 3 | 2.83 | 3.06 | 1.95 | −36.26 | 1992.03 | 0.00293 |
| | | [0.12] | [0.13] | [0.26] | [8.87] | [1991.01,1996.07] | |
| DETOTNS | 7 | 8.05 | 8.91 | 5.50 | −38.30 | 1990.11 | 0.000771 |
| | | [0.36] | [0.41] | [0.71] | [8.42] | [1989.09,1995.04] | |
| **Italy** | | | | | | | |
| ITIPSA | 7 | 21.75 | 24.62 | 15.74 | −36.06 | 1988.01 | 4.39E-005 |
| | | [0.88] | [1.05] | [1.51] | [6.71] | [1986.11,1992.01] | |
| ITLIND | 10 | 4.67 | 6.14 | 4.03 | −34.37 | 1977.04 | 6.49E-007 |
| | | [0.18] | [0.31] | [0.21] | [4.72] | [1976.03,1980.07] | |
| ITRSALE | 2 | 30.48 | 33.85 | 11.47 | −66.10 | 1996.06 | 2.42E-007 |
| | | [1.44] | [1.49] | [3.54] | [10.56] | [1996.04,1997.08] | |
| ITORDER | 12 | 74.40 | 81.52 | 63.55 | −22.04 | 1990.04 | 0.145 |
| | | [3.55] | [4.53] | [5.59] | [8.11] | [1985.06,2000.08] | |
| ITNCARR | 5 | 95.43 | 109.90 | 86.32 | −21.45 | 1976.06 | 0.0531 |
| | | [3.98] | [6.34] | [5.03] | [6.44] | [1970.04,1988.09] | |
| ITWAGES | 12 | 10.23 | 15.33 | 6.80 | −55.67 | 1977.02 | 8.15E-010 |
| | | [0.65] | [0.98] | [0.80] | [5.96] | [1976.11,1981.01] | |
| ITIMPOR | 12 | 74.67 | 90.82 | 40.89 | −54.98 | 1988.01 | 1.18E-010 |
| | | [3.49] | [4.05] | [5.85] | [6.75] | [1987.09,1990.02] | |
| ITEXPOR | 5 | 67.65 | 80.13 | 40.55 | −49.40 | 1988.05 | 1.46E-009 |
| | | [2.89] | [3.34] | [4.92] | [6.50] | [1988.02,1990.09] | |
| ITNMONS | 9 | 11.67 | 10.51 | 16.00 | 52.26 | 1993.11 | 0.00734 |
| | | [0.64] | [0.71] | [1.37] | [16.57] | [1989.08,1995.09] | |
| ITBMONS | 12 | 8.55 | 6.84 | 12.37 | 80.70 | 1991.11 | 2.03E-007 |
| | | [0.46] | [0.52] | [0.78] | [17.97] | [1989.09,1992.07] | |
| ITSIRAT | 1 | 555.58 | 986.92 | 450.46 | −54.36 | 1977.09 | 1.37E-005 |
| | | [43.51] | [94.83] | [46.82] | [6.46] | [1976.12,1981.04] | |
| ITLIRAT | 3 | 314.73 | 112.45 | 413.36 | 267.58 | 1974.02 | 5.16E-020 |
| | | [16.06] | [25.68] | [17.93] | [85.44] | [1972.11,1974.03] | |
| ITSTOCK | 3 | 64.36 | 49.55 | 70.79 | 42.88 | 1973.02 | 0.00204 |
| | | [2.53] | [4.52] | [2.98] | [14.35] | [1967.06,1974.11] | |
| ITEXRAT | 1 | 27.18 | 17.52 | 29.79 | 70.02 | 1980.02 | 0.00679 |
| | | [1.43] | [3.03] | [1.58] | [30.76] | [1977.05,1981.11] | |
| ITCPINS | 12 | 3.10 | 4.18 | 2.01 | −51.98 | 1981.02 | 2.13E-011 |
| | | [0.16] | [0.21] | [0.21] | [5.63] | [1980.11,1983.12] | |
| ITPPINS | 12 | 3.43 | 4.14 | 3.10 | −25.26 | 1988.02 | 0.220 |
| | | [0.22] | [0.38] | [0.26] | [9.21] | [1985.01,1999.08] | |
| ITTOTNS | 8 | 24.56 | 32.56 | 19.69 | −39.53 | 1984.03 | 1.37E-005 |
| | | [1.28] | [2.00] | [1.56] | [6.07] | [1983.03,1987.08] | |

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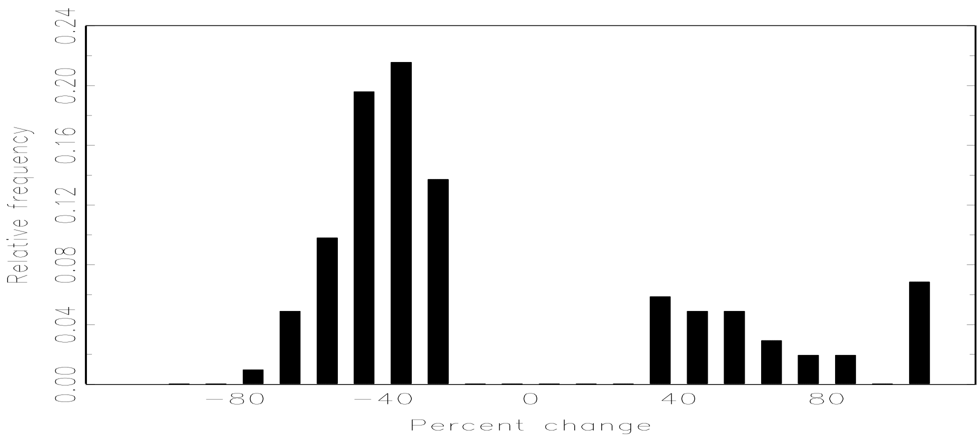
| Series | $p$ | $\sigma_0$ | $\sigma_1$ | $\sigma_2$ | $\Delta\sigma$ | $\tau_v$ | p-value |
|---|---|---|---|---|---|---|---|
| | | | | **Japan** | | | |
| JPIPSA | 12 | 14.40 | 13.61 | 17.26 | 26.86 | 1992.04 | 0.0547 |
| | | [0.52] | [0.59] | [1.12] | [9.85] | [1983.08,1997.08] | |
| JPLIND | 7 | 4.11 | 5.36 | 3.41 | −36.38 | 1975.05 | 9.49E-008 |
| | | [0.16] | [0.26] | [0.20] | [4.78] | [1974.02,1978.08] | |
| JPRSALE | 3 | 16.03 | 19.90 | 10.94 | −45.01 | 1983.09 | 5.05E-011 |
| | | [0.65] | [0.82] | [0.95] | [5.27] | [1983.01,1986.01] | |
| JPORDER | 12 | 101.71 | 122.19 | 71.08 | −41.83 | 1984.12 | 1.12E-008 |
| | | [4.12] | [5.11] | [6.24] | [5.66] | [1984.04,1987.10] | |
| JPNCARR | 12 | 50.70 | 72.70 | 42.96 | −40.91 | 1977.07 | 8.49E-007 |
| | | [2.42] | [4.56] | [2.71] | [5.26] | [1976.12,1981.06] | |
| JPUNEMP | 12 | 95.36 | 92.15 | 112.94 | 22.56 | 1994.10 | 0.264 |
| | | [3.43] | [3.71] | [8.69] | [10.64] | [1985.02,2000.12] | |
| JPWAGES | 12 | 6.66 | 11.58 | 3.83 | −66.92 | 1975.08 | 6.87E-022 |
| | | [0.41] | [0.61] | [0.47] | [4.39] | [1975.06,1976.11] | |
| JPULCOS | 12 | 14.98 | 12.11 | 16.25 | 34.23 | 1973.04 | 0.0276 |
| | | [0.61] | [1.10] | [0.73] | [13.57] | [1964.05,1975.12] | |
| JPIMPOR | 12 | 50.83 | 40.89 | 54.38 | 32.98 | 1971.07 | 0.0309 |
| | | [1.93] | [3.73] | [2.23] | [13.28] | [1963.08,1974.02] | |
| JPEXPOR | 12 | 40.13 | 48.52 | 35.47 | −26.90 | 1975.04 | 0.00204 |
| | | [1.62] | [2.67] | [1.99] | [5.73] | [1972.03,1982.05] | |
| JPNMONS | 9 | 10.34 | 11.49 | 6.68 | −41.80 | 1991.06 | 0.000147 |
| | | [0.46] | [0.51] | [0.92] | [8.40] | [1990.10,1995.01] | |
| JPBMONS | 12 | 3.48 | 5.82 | 3.01 | −48.16 | 1967.09 | 5.24E-010 |
| | | [0.16] | [0.38] | [0.17] | [4.43] | [1967.02,1970.01] | |
| JPSIRAT | 12 | 313.39 | 425.00 | 162.58 | −61.75 | 1986.12 | 2.02E-012 |
| | | [18.32] | [22.58] | [26.25] | [6.50] | [1986.07,1988.09] | |
| JPLIRAT | 3 | 261.29 | 53.53 | 343.67 | 541.99 | 1977.03 | 1.48E-018 |
| | | [15.58] | [26.53] | [16.71] | [319.73] | [1976.03,1977.04] | |
| JPSTOCK | 1 | 56.94 | 48.41 | 71.22 | 47.12 | 1986.01 | 3.60E-005 |
| | | [2.32] | [2.86] | [3.70] | [11.58] | [1981.04,1987.12] | |
| JPEXRAT | 3 | 31.29 | 22.92 | 33.08 | 44.33 | 1979.08 | 0.0911 |
| | | [1.45] | [3.42] | [1.58] | [22.60] | [1975.03,1982.09] | |
| JPCPINS | 12 | 5.83 | 7.20 | 3.84 | −46.64 | 1984.09 | 1.01E-011 |
| | | [0.24] | [0.29] | [0.35] | [5.33] | [1984.03,1986.11] | |
| JPPPINS | 3 | 4.78 | 3.91 | 5.14 | 31.45 | 1972.09 | 0.190 |
| | | [0.24] | [0.44] | [0.28] | [16.34] | [1961.02,1975.09] | |
| JPTOTNS | 1 | 12.32 | 8.10 | 14.10 | 74.06 | 1972.11 | 0.000515 |
| | | [0.65] | [1.18] | [0.76] | [26.98] | [1967.09,1973.06] | |
| | | | | **UK** | | | |
| UKIPSA | 5 | 12.64 | 14.27 | 8.02 | −43.79 | 1990.07 | 6.69E-008 |
| | | [0.47] | [0.53] | [0.89] | [6.57] | [1990.01,1992.10] | |
| UKLIND | 10 | 3.88 | 4.57 | 3.24 | −29.05 | 1980.11 | 0.00127 |
| | | [0.17] | [0.24] | [0.23] | [6.19] | [1979.05,1988.10] | |
| UKRSALE | 5 | 11.65 | 12.95 | 7.28 | −43.78 | 1991.10 | 1.23E-005 |
| | | [0.48] | [0.53] | [0.98] | [7.89] | [1991.04,1994.08] | |
| UKORDER | 4 | 81.13 | 71.36 | 88.19 | 23.57 | 1977.10 | 0.0661 |
| | | [2.96] | [4.53] | [3.85] | [9.53] | [1965.10,1983.11] | |
| UKNCARR | 5 | 83.44 | 99.25 | 59.73 | −39.82 | 1983.10 | 1.80E-006 |
| | | [3.66] | [4.57] | [5.60] | [6.29] | [1982.11,1987.04] | |
| UKUNEMP | 4 | 82.42 | 64.12 | 88.40 | 37.86 | 1970.11 | 0.00895 |
| | | [3.02] | [6.01] | [3.43] | [13.98] | [1965.07,1974.04] | |
| UKWAGES | 12 | 9.30 | 12.69 | 5.64 | −55.51 | 1983.03 | 3.18E-016 |
| | | [0.44] | [0.56] | [0.59] | [5.03] | [1982.11,1984.11] | |
| UKULCOS | 8 | 13.55 | 14.76 | 7.88 | −46.62 | 1994.06 | 5.11E-005 |
| | | [0.56] | [0.60] | [1.30] | [9.08] | [1993.12,1996.10] | |
| UKIMPOR | 11 | 44.58 | 50.94 | 33.62 | −34.00 | 1986.04 | 4.73E-005 |
| | | [1.77] | [2.18] | [2.86] | [6.28] | [1984.10,1990.07] | |
| UKEXPOR | 10 | 45.04 | 52.02 | 39.81 | −23.46 | 1978.02 | 0.00723 |
| | | [1.71] | [2.58] | [2.24] | [5.74] | [1974.09,1987.04] | |
| UKNMONS | 12 | 6.36 | 9.26 | 4.64 | −49.89 | 1981.10 | 8.66E-018 |
| | | [0.27] | [0.40] | [0.31] | [4.01] | [1981.05,1983.01] | |
| UKBMONS | 6 | 4.66 | 4.27 | 6.83 | 59.73 | 1998.04 | 0.0169 |
| | | [0.28] | [0.30] | [0.71] | [20.07] | [1995.04,1999.07] | |
| UKSIRAT | 2 | 499.30 | 581.26 | 159.15 | −72.62 | 1993.03 | 8.17E-008 |
| | | [28.81] | [30.94] | [63.04] | [10.94] | [1993.01,1994.01] | |
| UKLIRAT | 2 | 381.73 | 201.90 | 452.30 | 124.03 | 1972.04 | 2.71E-010 |
| | | [17.12] | [30.75] | [19.26] | [35.43] | [1970.04,1972.06] | |
| UKSTOCK | 5 | 46.62 | 33.25 | 50.47 | 51.81 | 1969.12 | 0.00626 |
| | | [2.01] | [4.20] | [2.25] | [20.34] | [1964.09,1971.07] | |
| UKEXRAT | 3 | 27.53 | 30.74 | 19.89 | −35.28 | 1993.04 | 0.00249 |
| | | [1.31] | [1.52] | [2.35] | [8.29] | [1992.01,1996.12] | |
| UKCPINS | 12 | 4.18 | 5.09 | 3.23 | −36.41 | 1981.05 | 8.97E-005 |
| | | [0.20] | [0.28] | [0.28] | [6.55] | [1980.04,1987.05] | |

*continued on next page*

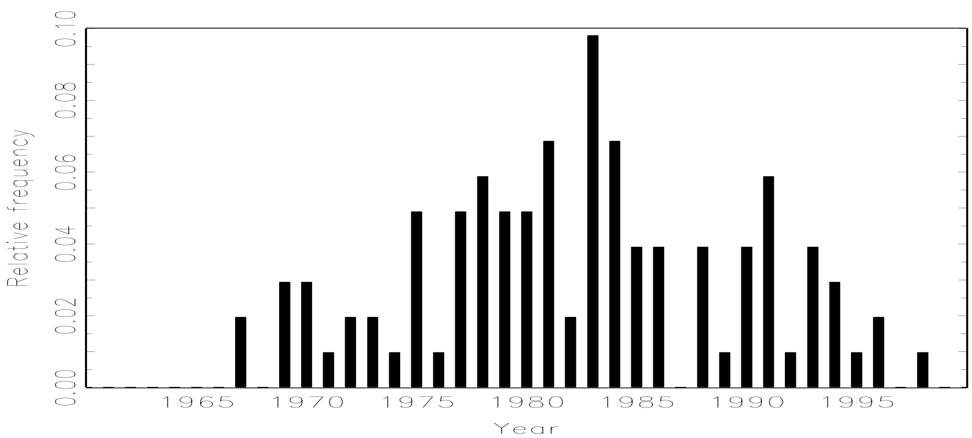
*continued from previous page*

| Series | $p$ | $\sigma_0$ | $\sigma_1$ | $\sigma_2$ | $\Delta\sigma$ | $\tau_v$ | p-value |
|---|---|---|---|---|---|---|---|
| UKPPINS | 7 | 4.54 | 5.86 | 3.17 | −45.92 | 1981.05 | 1.37E-010 |
| | | [0.20] | [0.27] | [0.27] | [5.30] | [1980.11,1984.02] | |
| UKTOTNS | 12 | 11.16 | 12.17 | 6.58 | −45.93 | 1995.07 | 0.0226 |
| | | [0.68] | [0.74] | [1.57] | [13.34] | [1995.01,1999.11] | |
| | | | | **US** | | | |
| USIPSA | 3 | 7.91 | 9.36 | 5.92 | −36.72 | 1984.03 | 1.90E-005 |
| | | [0.35] | [0.44] | [0.52] | [6.34] | [1983.03,1988.11] | |
| USLIND | 12 | 5.72 | 6.75 | 4.41 | −34.68 | 1983.05 | 4.88E-005 |
| | | [0.25] | [0.32] | [0.36] | [6.23] | [1982.02,1988.06] | |
| USRSALE | 2 | 11.95 | 13.93 | 8.72 | −37.44 | 1985.10 | 2.33E-006 |
| | | [0.48] | [0.59] | [0.76] | [6.06] | [1984.08,1989.04] | |
| USORDER | 6 | 22.38 | 23.25 | 18.79 | −19.19 | 1993.03 | 0.251 |
| | | [0.80] | [0.88] | [1.80] | [8.31] | [1988.02,2000.12] | |
| USNCARR | 9 | 60.83 | 65.55 | 46.07 | −29.71 | 1991.01 | 0.0149 |
| | | [2.52] | [2.86] | [5.06] | [8.31] | [1988.07,1997.03] | |
| USUNEMP | 12 | 173.94 | 190.63 | 145.71 | −23.56 | 1986.02 | 0.0322 |
| | | [7.09] | [8.85] | [11.51] | [7.01] | [1982.07,1996.05] | |
| USWAGES | 12 | 3.89 | 4.51 | 3.10 | −31.23 | 1983.04 | 0.000160 |
| | | [0.16] | [0.21] | [0.23] | [6.01] | [1981.02,1988.05] | |
| USIMPOR | 12 | 45.15 | 53.42 | 19.56 | −63.39 | 1991.03 | 5.93E-012 |
| | | [2.07] | [2.25] | [3.96] | [7.57] | [1991.01,1992.09] | |
| USEXPOR | 12 | 42.32 | 48.59 | 28.45 | −41.45 | 1988.07 | 7.78E-007 |
| | | [1.71] | [2.00] | [2.98] | [6.58] | [1988.01,1991.08] | |
| USNMONS | 9 | 4.60 | 3.42 | 5.59 | 63.64 | 1979.03 | 7.39E-008 |
| | | [0.19] | [0.27] | [0.24] | [14.61] | [1976.03,1980.06] | |
| USBMONS | 10 | 2.36 | 1.77 | 2.54 | 43.50 | 1970.01 | 0.0220 |
| | | [0.10] | [0.21] | [0.11] | [18.21] | [1963.05,1971.11] | |
| USSIRAT | 12 | 394.64 | 489.91 | 243.25 | −50.35 | 1985.07 | 4.26E-006 |
| | | [23.30] | [28.91] | [36.44] | [8.00] | [1985.05,1990.01] | |
| USLIRAT | 12 | 297.32 | 191.89 | 386.87 | 101.61 | 1979.05 | 1.51E-013 |
| | | [13.06] | [18.12] | [16.70] | [20.93] | [1977.03,1979.09] | |
| USSTOCK | 2 | 36.72 | 38.66 | 30.78 | −20.38 | 1991.02 | 0.243 |
| | | [1.52] | [1.74] | [3.05] | [8.66] | [1983.11,2000.12] | |
| USCPINS | 9 | 2.52 | 2.91 | 2.02 | −30.46 | 1983.05 | 0.000400 |
| | | [0.10] | [0.14] | [0.15] | [6.17] | [1980.12,1988.11] | |
| USPPINS | 12 | 4.81 | 3.97 | 5.15 | 29.84 | 1972.06 | 0.0939 |
| | | [0.20] | [0.37] | [0.24] | [13.56] | [1961.03,1976.05] | |
| USTOTNS | 5 | 14.39 | 20.71 | 10.65 | −48.56 | 1981.07 | 3.82E-012 |
| | | [0.70] | [1.06] | [0.82] | [4.75] | [1980.12,1983.05] | |

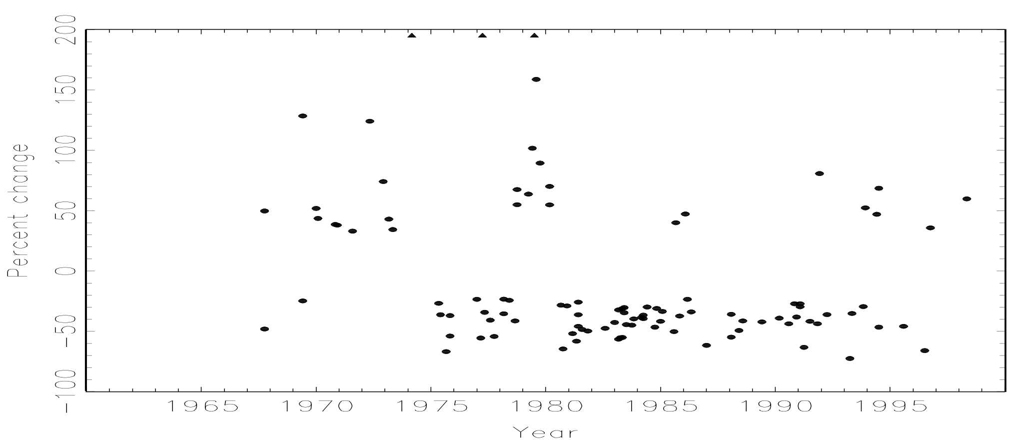
Results for SupW tests for structural change in conditional volatility for individual series, when using a linear AR model with constant parameters for the conditional mean. The column headed $\sigma_0$ contains the estimate of the conditional standard deviation under the null hypothesis. Columns headed $\sigma_1$ and $\sigma_2$ contain estimates of the conditional standard deviation before and after the break, respectively. The column headed $\Delta\sigma$ contains the percent change in standard deviation. The estimated break date is given in the column headed $\tau_v$, with the 90% confidence interval for the break date given in brackets. The final column contains the asymptotic $p$-value of the SupW test. Figures in brackets below parameter estimates are standard errors.




(a) Distribution of percent change in conditional standard deviation




(b) Distribution of break dates




(c) Scatter of break dates against percent change in standard deviation

Figure 1: Characteristics of conditional volatility breaks for series for which the SupW statistic is significant at the 5% level (102), when using a linear AR model with constant parameters for the conditional mean. In panel (a), series for which the standard deviation more than doubles are collected in the right-most category. In panel (c), series for which the standard deviation more than triples are shown as triangles.

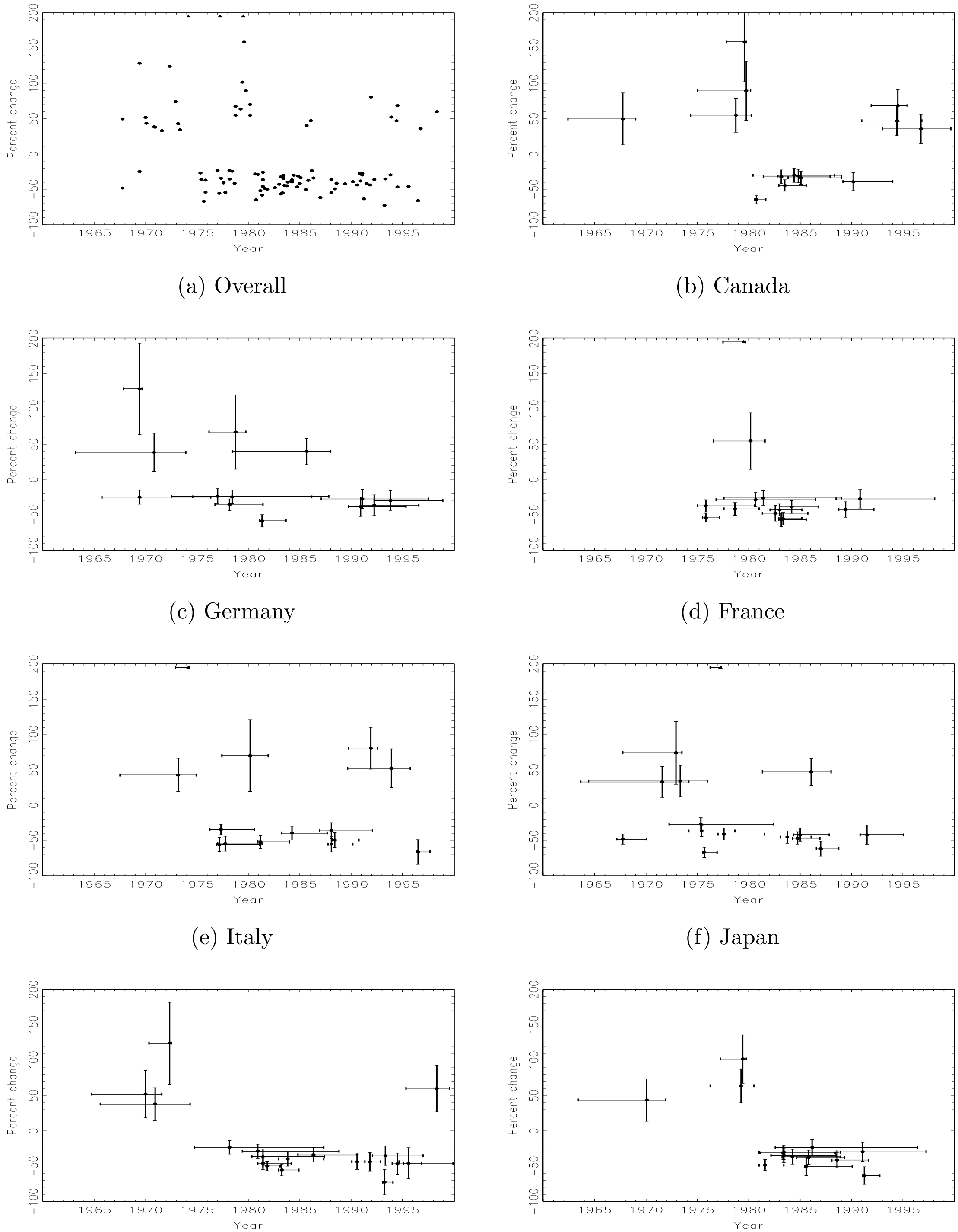
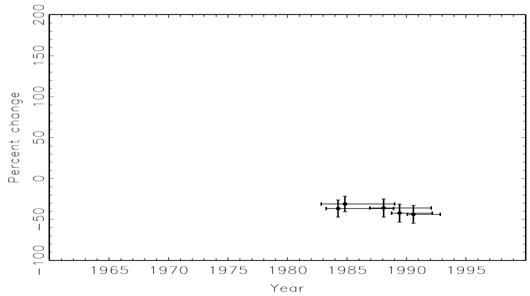
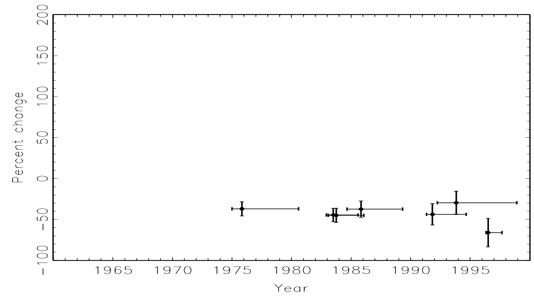


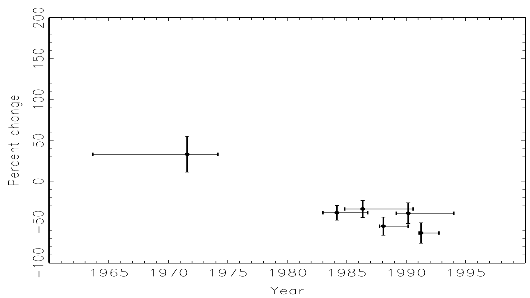

Figure 2: Scatter plots of volatility break dates against percent change in conditional standard deviation for series for which the SupW statistic is significant at the 5% level, when using a linear AR model with constant parameters for the conditional mean. In the graphs for the individual countries, 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



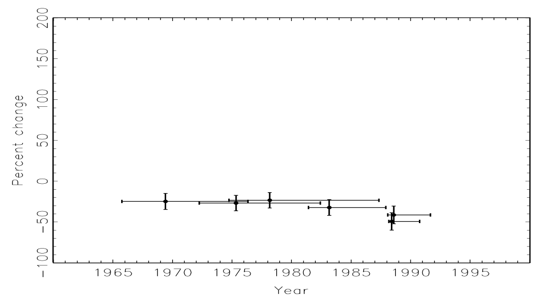

(a) Industrial Production



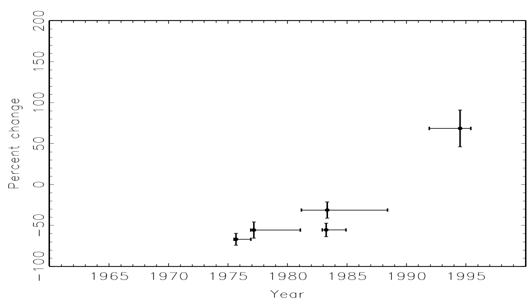

(b) Retail Sales



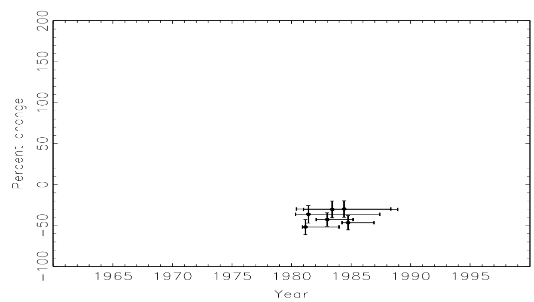

(c) Imports



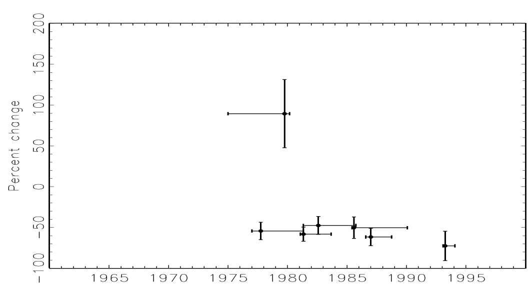

(d) Exports



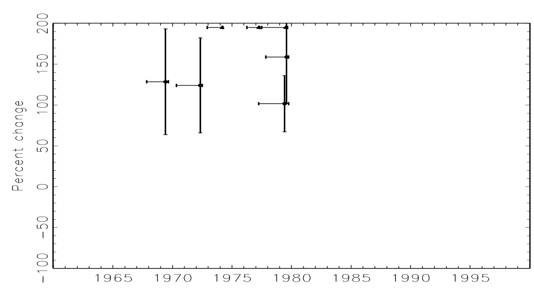

(e) Wages




(f) Consumer Prices

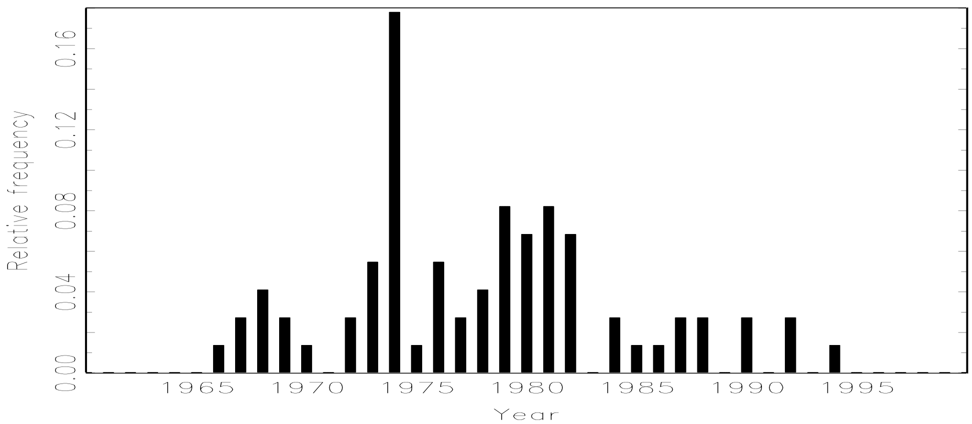



(g) ST Interest Rates

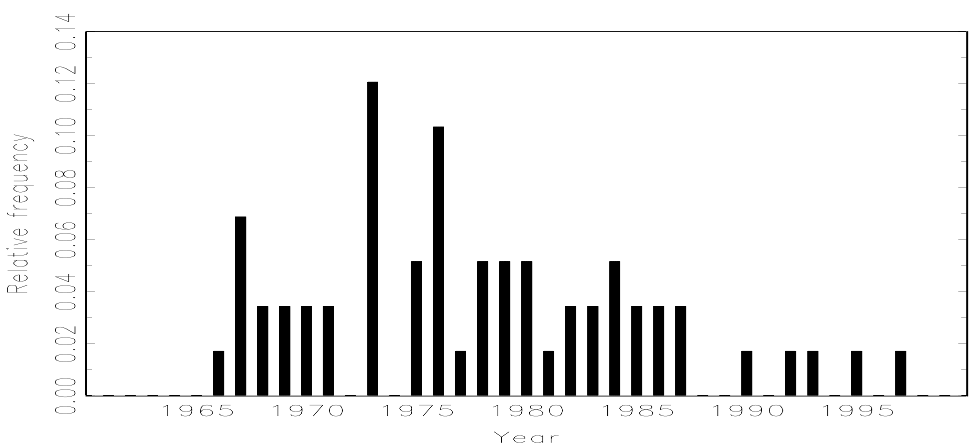



(h) LT Interest Rates

Figure 3: Scatter plots of volatility break dates against percent change in conditional standard deviation for series for which the SupW statistic is significant at the 5% level, when using a linear AR model with constant parameters for the conditional mean. 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.

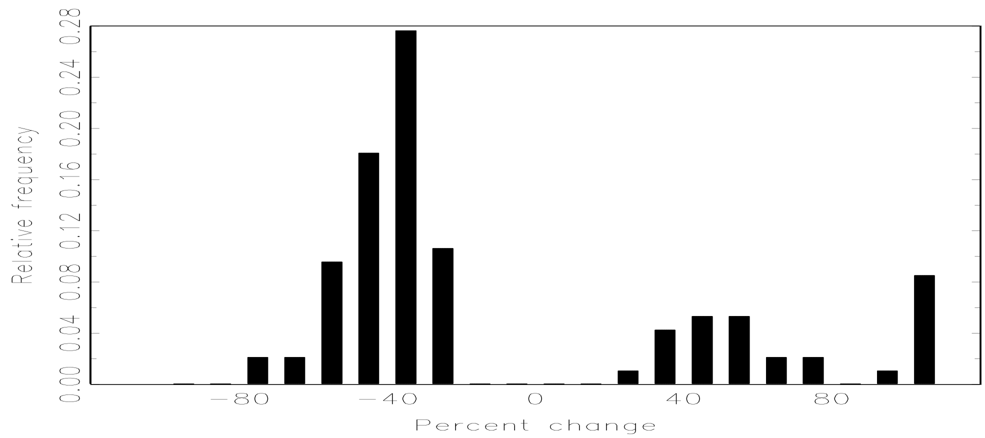



(a) Distribution of break dates in conditional mean - linear AR model

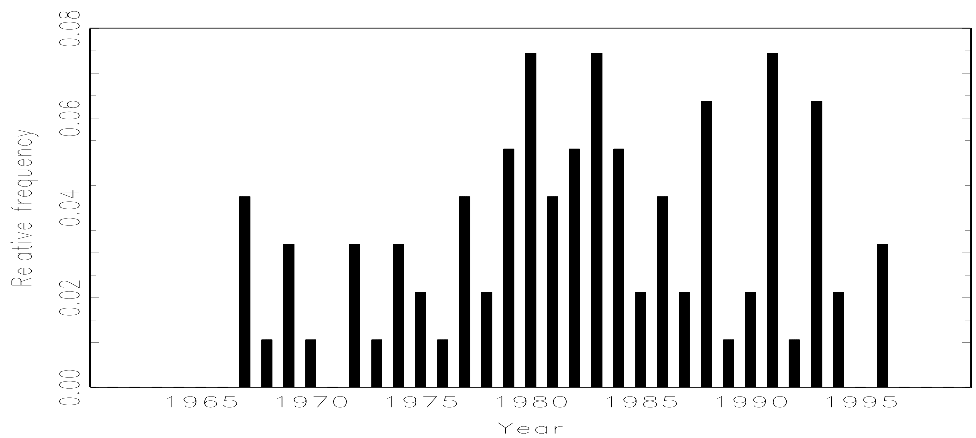



(b) Distribution of break dates in conditional mean - nonlinear AR model

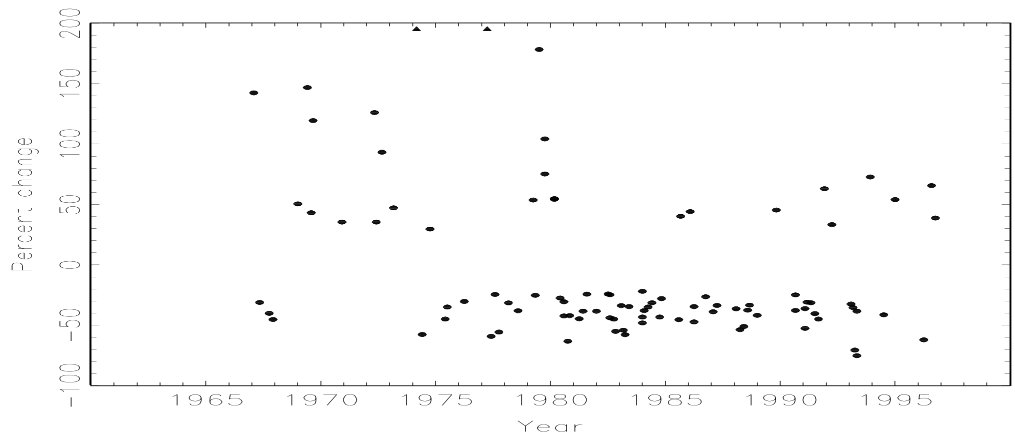
Figure 4: Break dates for series for which the SupW statistic for a structural change in the parameters in the linear model (1) or in the parameters during expansions in the nonlinear model (3) for the conditional mean is significant at 5% level (73 and 66, respectively).




(a) Distribution of percent change in standard deviation

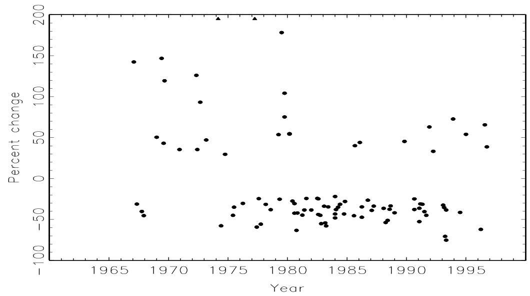



(b) Distribution of break dates

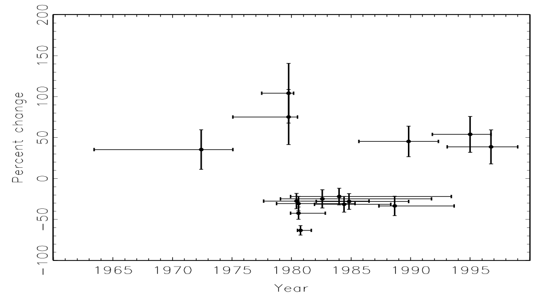



(c) Scatter of break dates against percent change in standard deviation

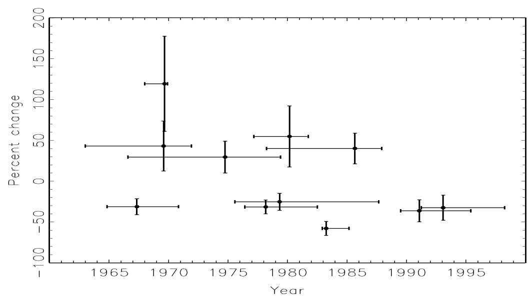
Figure 5: Characteristics of conditional volatility breaks for series for which the SupW statistic is significant at the 5% level (97), when using a nonlinear AR model with a single structural change during expansions for the conditional mean. In panel (a), series for which the standard deviation more than doubles are collected in the right-most category. In panel (c), series for which the standard deviation more than triples are shown as triangles.



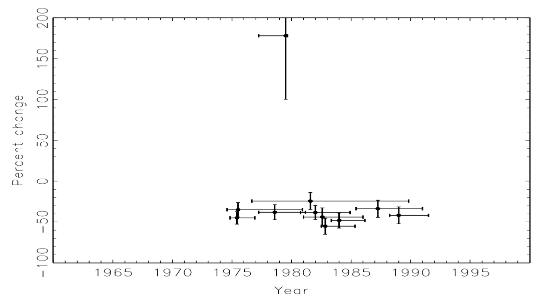

(a) Overall



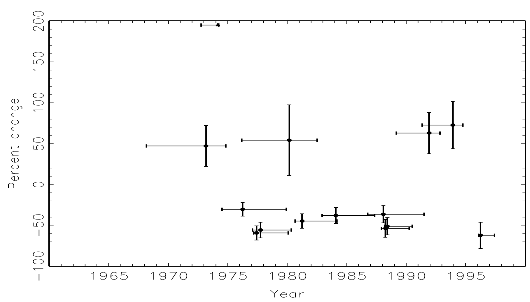

(b) Canada



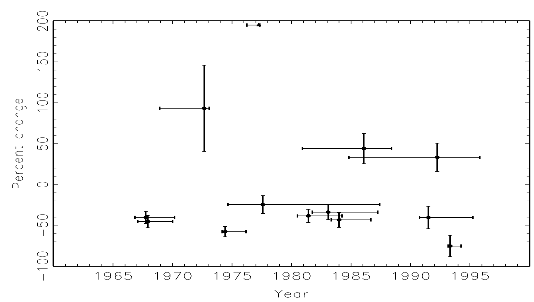

(c) Germany



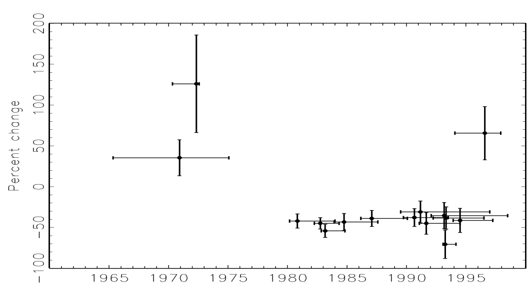

(d) France



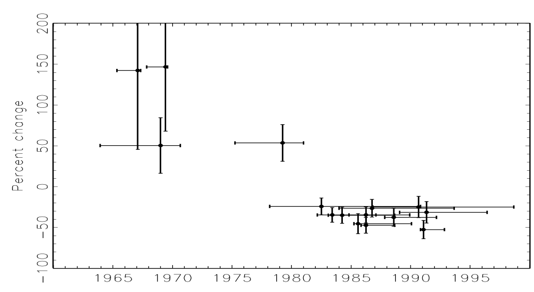

(e) Italy




(f) Japan

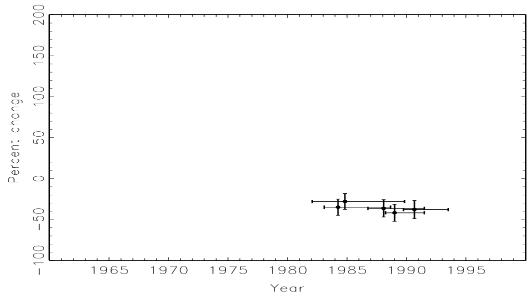



(g) UK

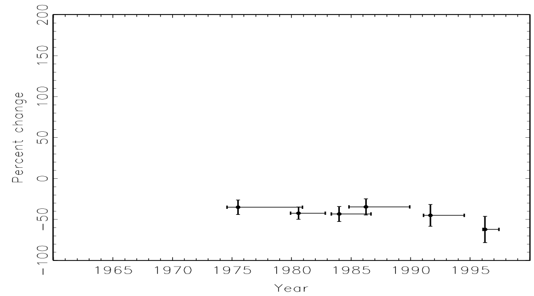



(h) US

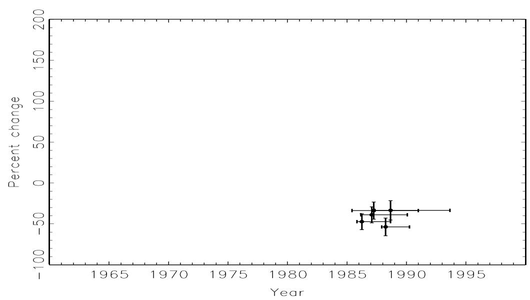
Figure 6: Scatter plots of volatility break dates against percent change in conditional standard deviation for series for which the SupW statistic is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. In the graphs for the individual countries, 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



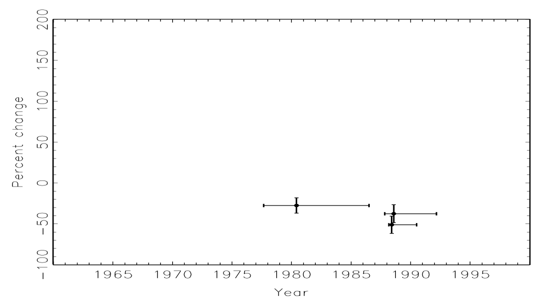

(a) Industrial Production



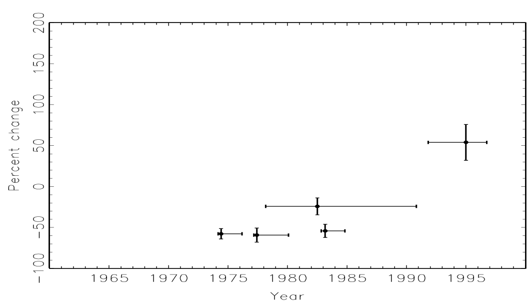

(b) Retail Sales



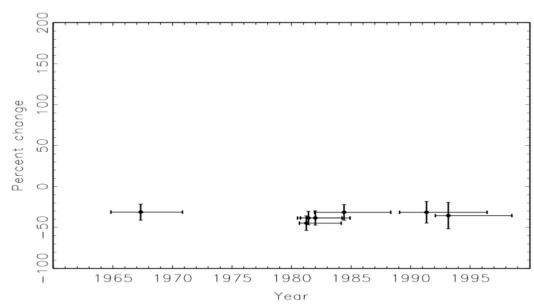

(c) Imports



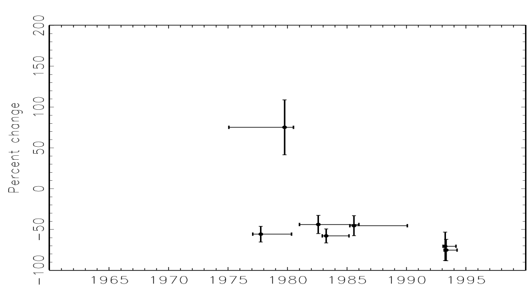

(d) Exports



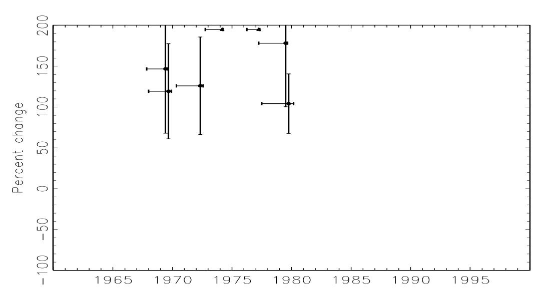

(e) Wages




(f) Consumer Prices

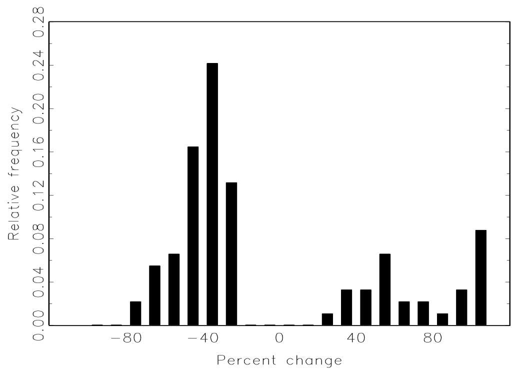



(g) ST Interest Rates

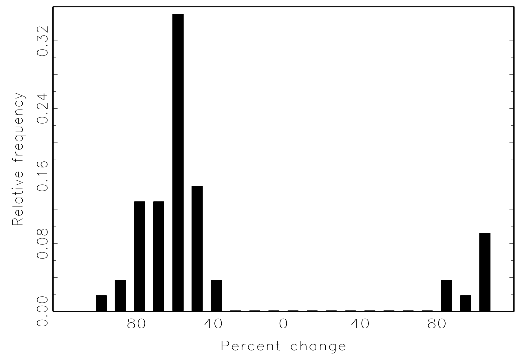



(h) LT Interest Rates

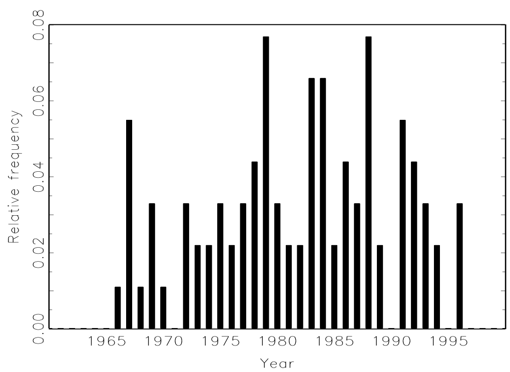
Figure 7: Scatter plots of volatility break dates against percent change in conditional standard deviation for series for which the SupW statistic is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



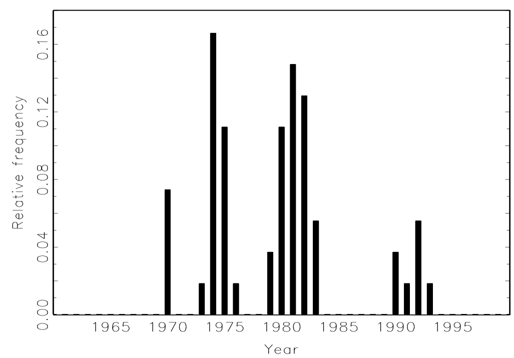

(a) Distribution of percent change in standard deviation during expansions



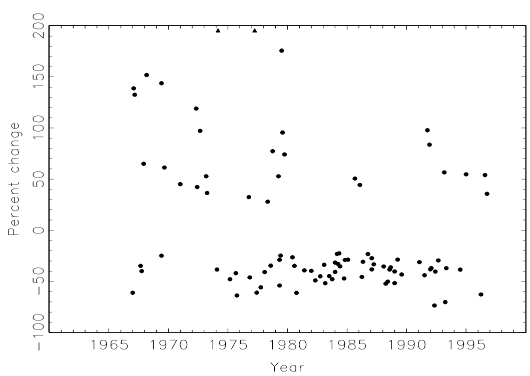

(b) Distribution of percent change in standard deviation during recessions



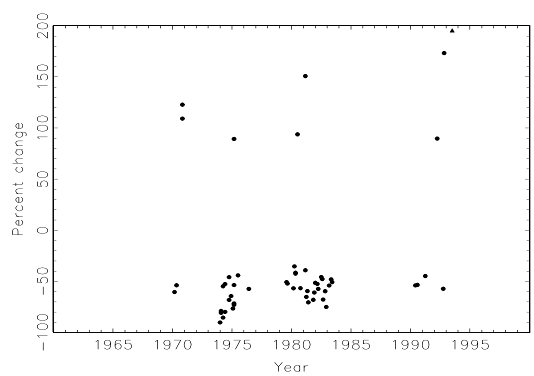

(c) Distribution of break dates for standard deviation during expansions




(d) Distribution of break dates for standard deviation during recessions

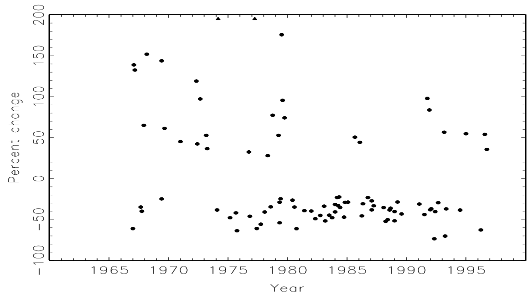



(e) Scatter of break dates against percent change in standard deviation during expansions

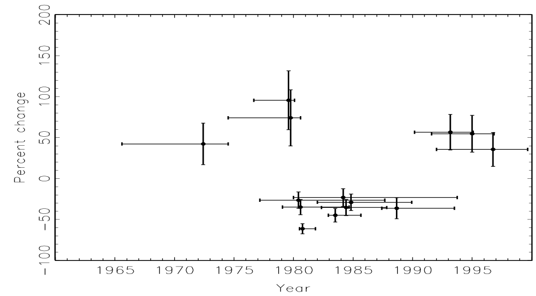



(f) Scatter of break dates against percent change in standard deviation during recessions

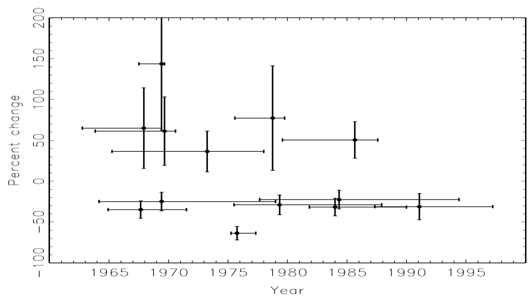
Figure 8: Characteristics of conditional volatility breaks for series for which the SupW statistics for a structural change in the conditional volatility in recessions and expansions separately are significant at the 5% level (91 and 54), when using a nonlinear AR model with a single structural change during expansions for the conditional mean. In panels (a) and (b), series for which the standard deviation more than doubles are collected in the right-most category. In panels (e) and (f), series for which the standard deviation more than triples are shown as triangles.



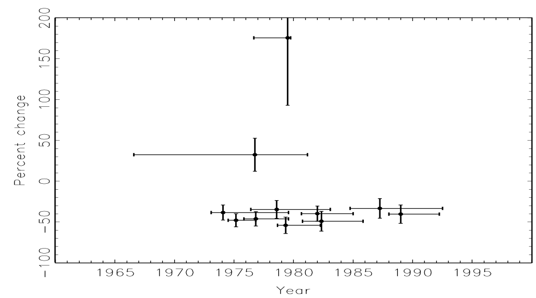

(a) Overall



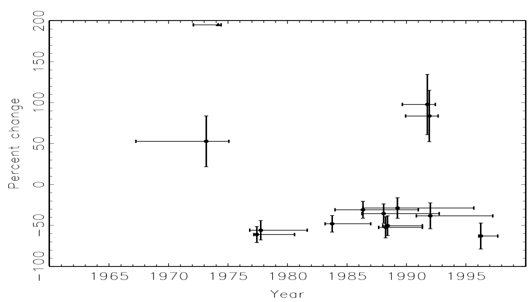

(b) Canada



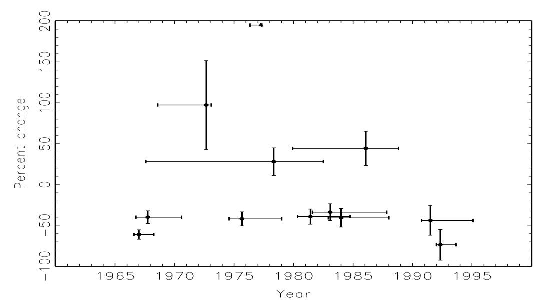

(c) Germany



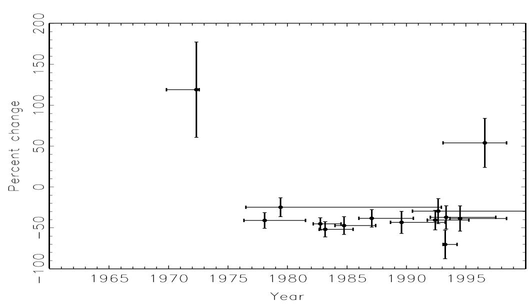

(d) France



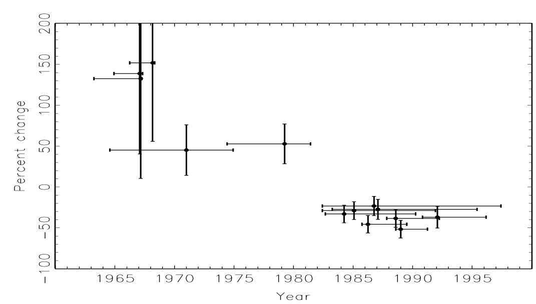

(e) Italy




(f) Japan

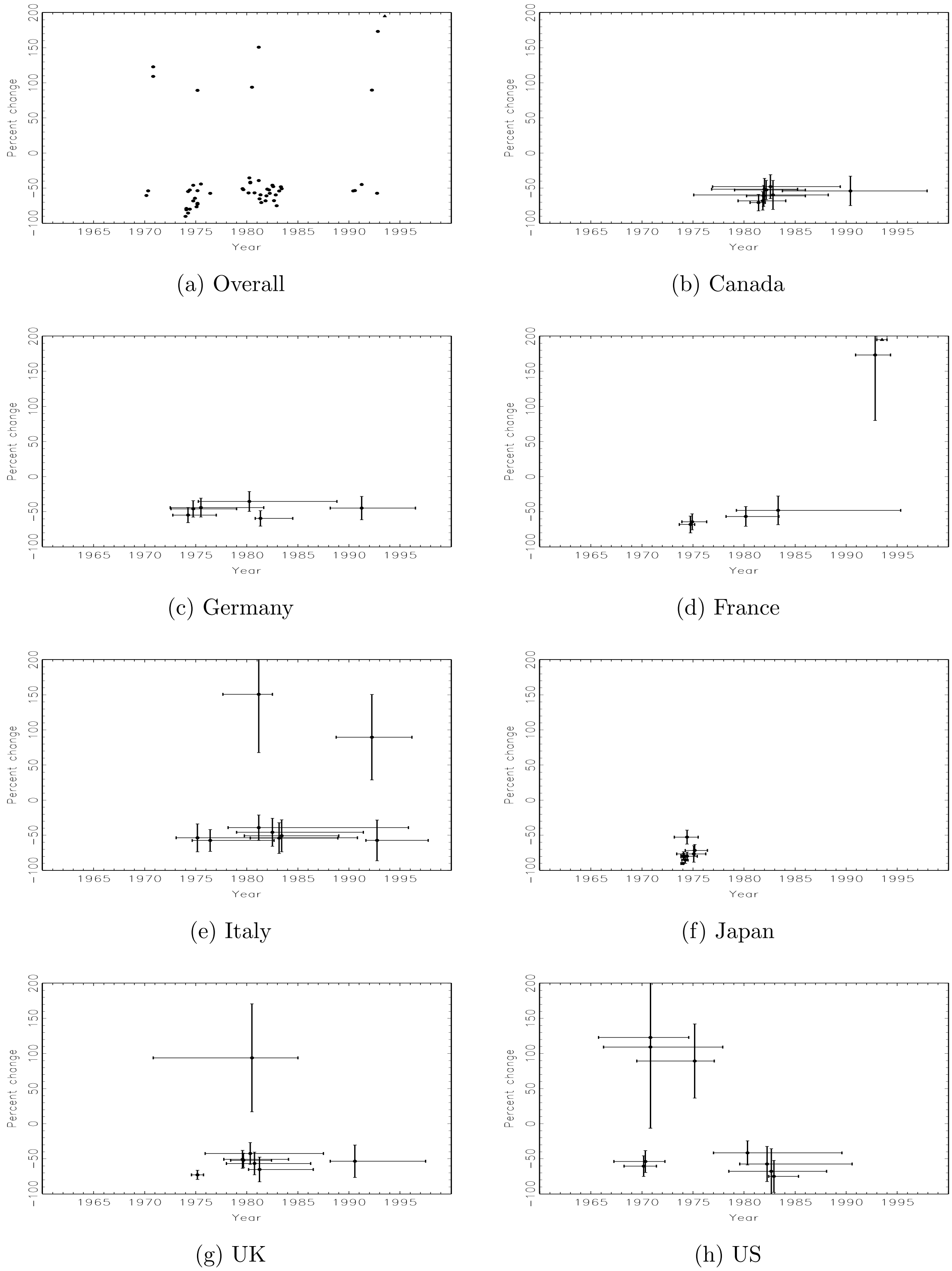



(g) UK




(h) US

Figure 9: Scatter plots of volatility break dates against percent change in conditional standard deviation during expansions for series for which the SupW statistic for a structural change in the conditional volatility in expansions only is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. In the graphs for the individual countries, 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



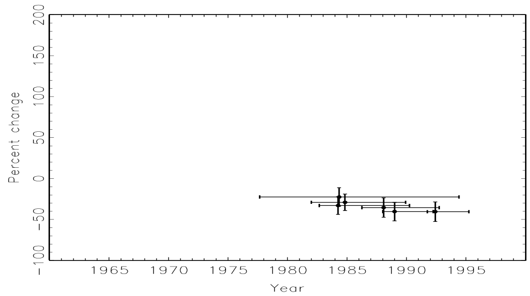

(a) Overall (b) Canada

(c) Germany (d) France

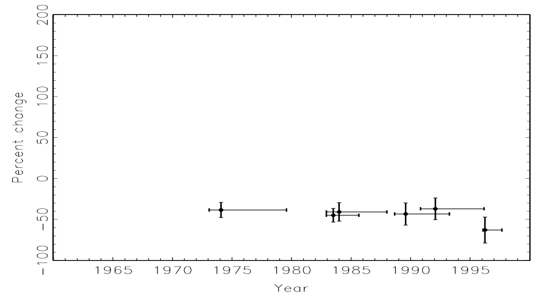
(e) Italy (f) Japan

(g) UK (h) US

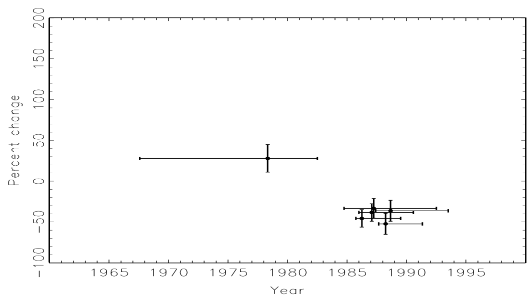
Figure 10: Scatter plots of volatility break dates against percent change in conditional standard deviation during recessions for series for which the SupW statistic for a structural change in the conditional volatility in recessions only is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. In the graphs for the individual countries, 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



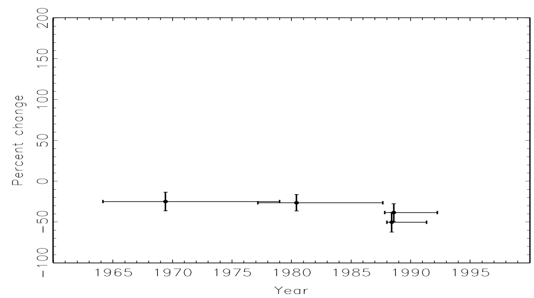

(a) Industrial Production



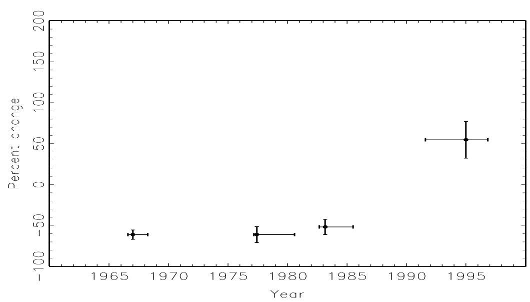

(b) Retail Sales



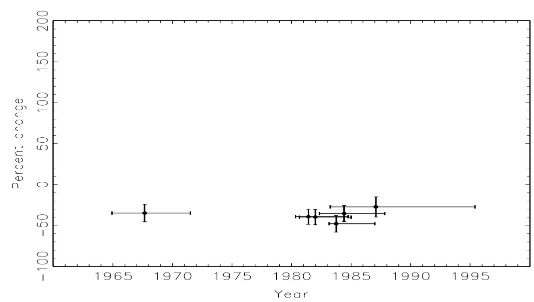

(c) Imports



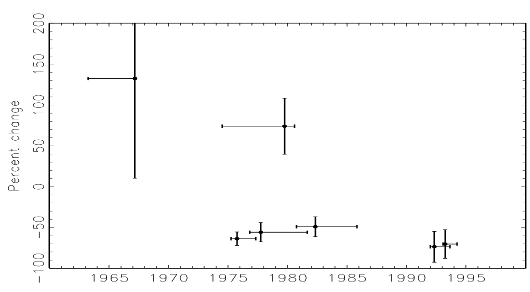

(d) Exports



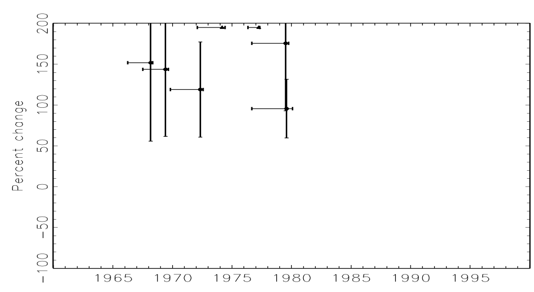

(e) Wages




(f) Consumer Prices

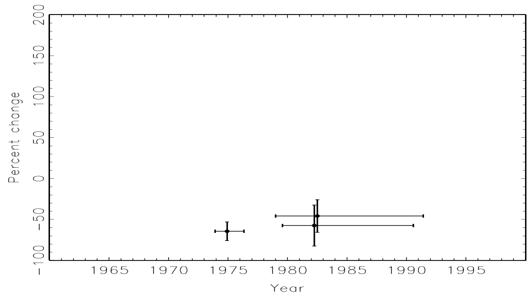



(g) ST Interest Rates

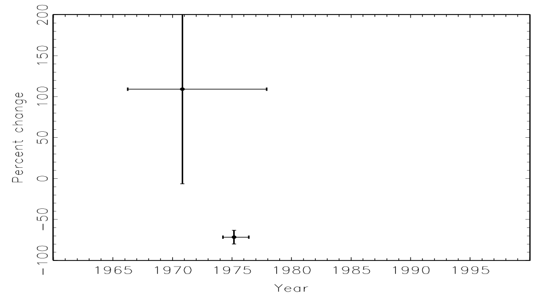



(h) LT Interest Rates

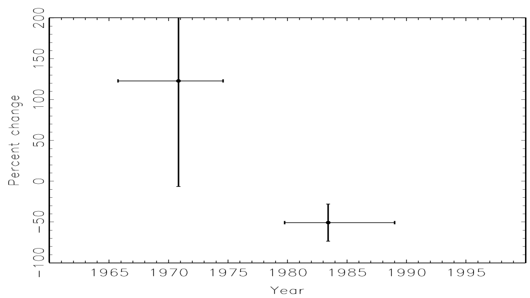
Figure 11: Scatter plots of volatility break dates against percent change in conditional standard deviation during expansions for series for which the SupW statistic for a structural change in the conditional volatility in expansions only is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.



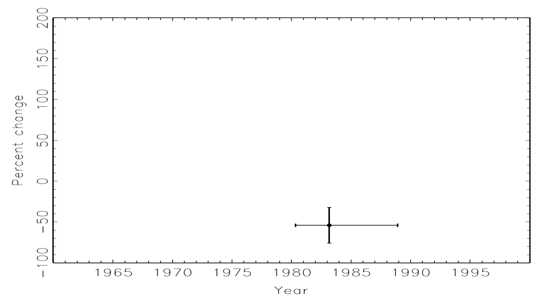

(a) Industrial Production



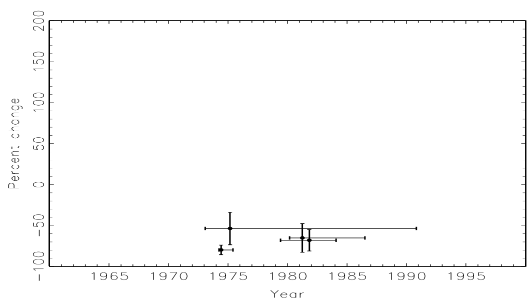

(b) Retail Sales



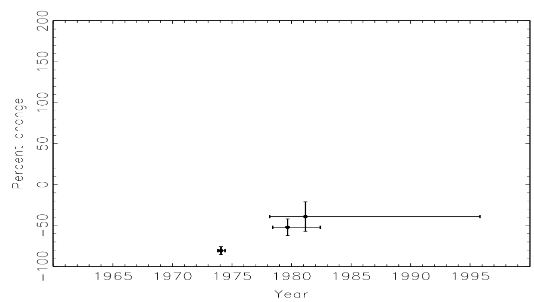

(c) Imports



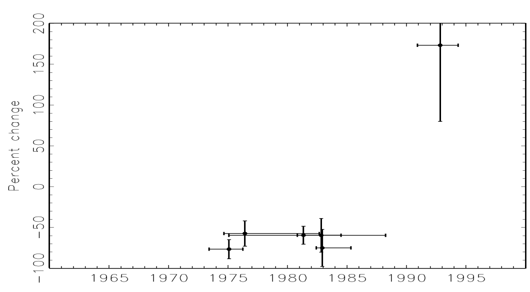

(d) Exports



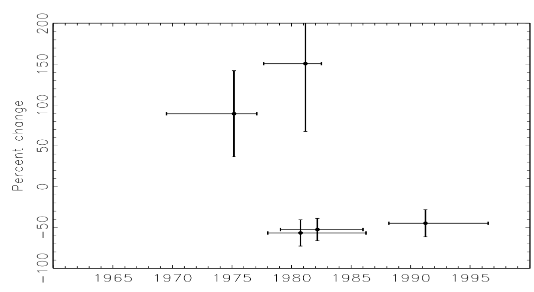

(e) Wages




(f) Consumer Prices

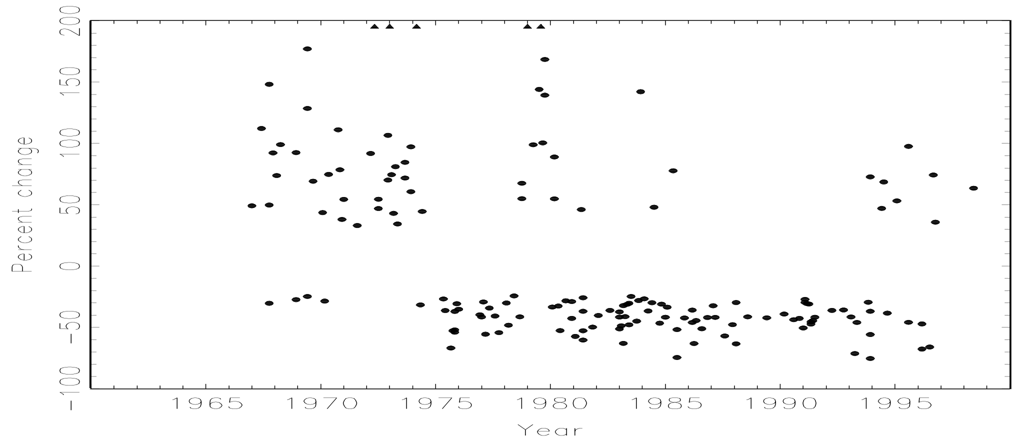



(g) ST Interest Rates

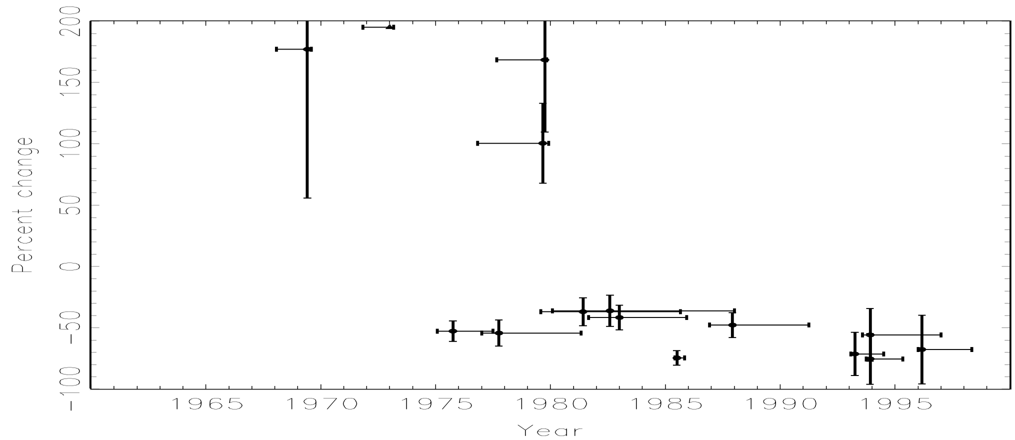



(h) LT Interest Rates

Figure 12: Scatter plots of volatility break dates against percent change in conditional standard deviation during recessions for series for which the SupW statistic for a structural change in the conditional volatility in recessions only is significant at the 5% level, when using a nonlinear AR model with a single structural change during expansions for the conditional mean. 90% confidence intervals for the break date and the percent change in standard deviation are included. Series for which the standard deviation more than triples are shown as triangles.




(a) Scatter of break dates against percent change in standard deviation




(b) Scatter of break dates against percent change in standard deviation for ST Interest Rates

Figure 13: Characteristics of structural changes in the conditional volatility detected with the sequential procedure of Bai (1997b) and Bai and Perron (1998) using a 5% significance level (147), when using a nonlinear AR model with a single structural change during expansions only for the conditional mean. In panel (b), 90% confidence intervals for the break date and the percent change in standard deviation are included. Breaks for which the standard deviation more than triples are shown as triangles.