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Output Volatility in Australia

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A number of papers have documented a significant decline in real GDP volatility in several major OECD economies. Some authors have presented evidence to suggest that this is the outcome of a one-off structural break from a high to low volatility state whilst others have estimated regime switching models that indicate low volatility regime states have dominated in recent years. This paper provides further evidence on the decline in output volatility for Australia. Evidence is provided of a significant shift to a low volatility regime in the mid1980's. The paper also provides estimates of various GARCH models of real GDP growth to further examine shorter term volatility features of the economy associated with the business cycle. A regime shift dummy is maintained in all models of the conditional variance to account for the decline in volatility and evidence is provided of significant business cycle effects, including asymmetries that suggest recessions are times of higher output volatility than economic expansions.

1. Introduction

Several studies have documented a significant decline in the volatility of macroeconomic variables, in particular real GDP, for countries in the G7. The coincident nature and extent of this phenomenon across many countries has earned it the label of 'the Great Moderation' amongst some authors.[2] For the US, papers of particular interest are Summers (2005), Blanchard and Simon (2001), McConnell and Perez-Quiros (2000), McConnell, Mosser and Perez-Quiros (1999), Kim and Nelson (1999) and Kahn, McConnell and Perez-Quiros (1999). For New Zealand evidence see the papers by Buckle, Haugh and Thompson (2000a,b). Some Australian evidence has previously been provided by Smith and Summers (2002) and Simon (2001).

This paper provides further evidence regarding the decline in output volatility in Australia. It documents the time period around which real GDP growth may have entered a new low volatility regime and provides some analysis of what might be the underlying source of this persistent, dramatic decline.

The paper also provides estimates of various GARCH models of real GDP growth to further examine the possibility of volatility changes associated with the business cycle. A regime shift dummy is maintained in all models of the conditional variance to account for the decline in volatility. Various GARCH, TARCH and GARCH-Y models are then estimated and evidence is provided of significant business cycle effects, including significant asymmetries that suggest recessions are times of higher output volatility than are economic expansions.[3]

2. Basic Evidence

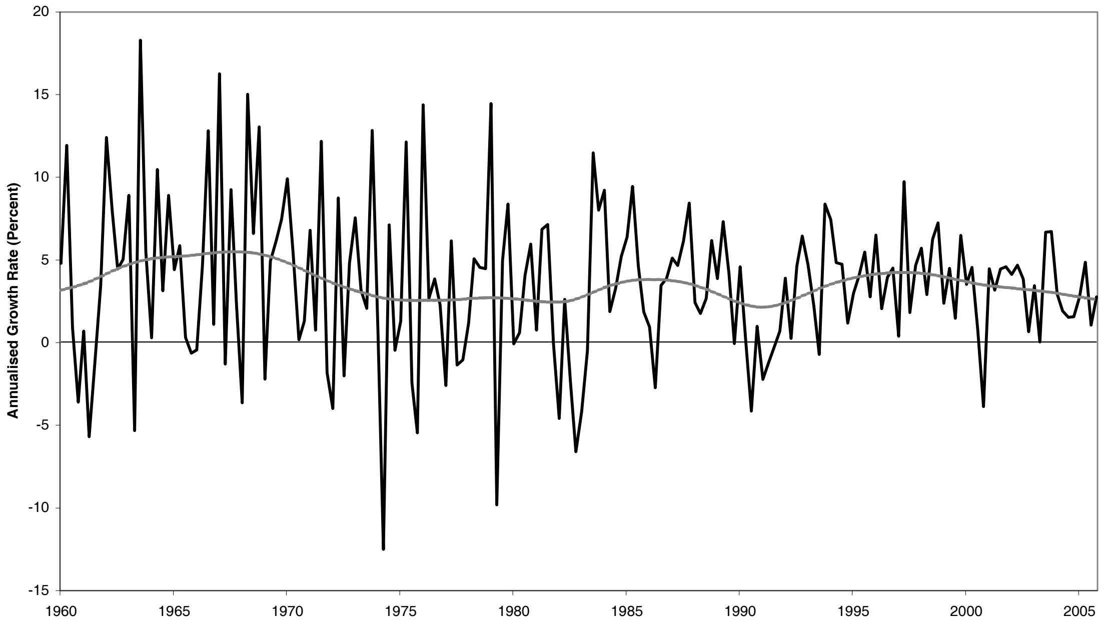
A simple plot of Australian real GDP growth illustrates how the quarter-to-quarter fluctuations in output appear to have diminished over time, particularly since the early-1980s. A simple HP filter ($\lambda = 10{,}000$) measure of the trend in real GDP growth also illustrates the

[2] See Summers(2005) and Bernanke(2004).

[3] Such evidence regarding both long-run and short-run changes in volatility are often ignored in discussion of so-called 'key features' or 'stylised facts' regarding business cycles. A recent paper by Cashin and Ouliaris (2004) is an example of such for Australia.

high, and possibly increasing, growth rate phase of the 1960s in contrast to the lower average growth rates experienced in Australia since the early 1970s.

Figure 1
Australian Real GDP Growth 1960:1 – 2004:4 (Annualised)



Source: ABS National Accounts in dX Database and authors calculations

Table 1 documents average quarterly annualised growth rates for each of the last four decades and for the period since 2000 and further illustrates the fact that there has been a significant decline in real GDP volatility since the 1970s, using the standard deviation of real GDP growth rates as a simple measure of variability. Also included are the relevant moment statistics for two potential structural break dates, one in the early 1970s associated with a potential shift in the mean growth rate and one in the early 1980s where a break in volatility seems most likely to have occurred. Finally, the mean and volatility measures are given for the expansion period following the 1990s recession, a period often described as one of strong growth and unprecedented stability, at least post WWII.

Of course, many papers have now documented the decline in volatility in the US economy starting in the mid-1980s, although there has been some debate over whether the decline has been smooth or due to a one-off shift, as well as potential causes of the decline (See McConnell and Perez-Quiros(2000), and Blanchard and Simon (2000)). These papers find no apparent break in the mean growth rate of GDP (no shift in potential GDP) for the US despite the much discussed productivity slowdown in the 1980s and the 'IT revolution' beginning in the mid to late 1990s.

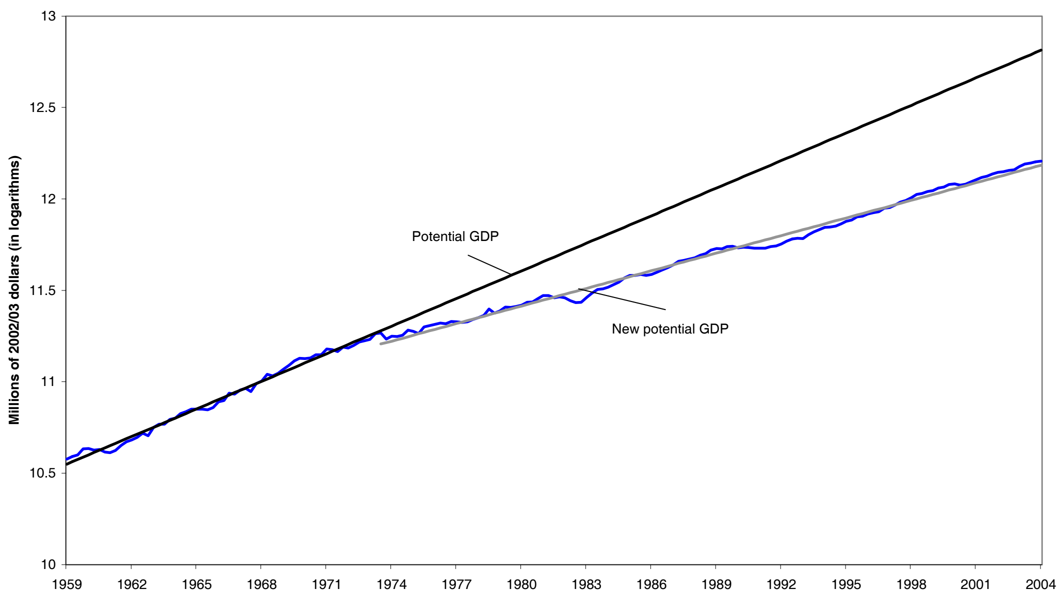
Table 1 Summary Statistics Annualised Growth in Real GDP, 1960-2005

Sample Period	Mean (%)	Std Dev (%)
1960:1-2005:4	3.54	4.69
1960:1-1969:4	4.98	6.37
1970:1-1979:4	3.19	6.09
1980:1-1989:4	3.19	3.94
1990:1-1999:4	3.32	2.72
2000:1-2005:4	2.97	2.29
1960:1-1971:3	5.00	6.12
1971:4-2005:4	3.16	4.23
1960:1-1982:1	3.90	6.07
1982:2-2005:4	3.28	3.23
1993:1-2005:4	3.65	2.46

Source: ABS National Accounts in dX Database and authors calculations

In Australia however, as well as an apparent, similar decline in volatility to the US in the mid-1980s, there is also evidence of a significant break in mean GDP growth in the early 1970s. The permanent fall in average GDP growth in the early 1970s in Australia, from around 5% per annum to just over 3% per annum, is fairly similar in timing and magnitude to the fall experienced in Canada, although the evidence provided in Voss (2004) and Debs (2001) suggests Canada seems to have experienced *increasing* volatility in GDP growth in the 1980s and 1990s – the opposite of the Australian and US experience. Figure 2 illustrates the permanent slowdown in the Australian around the time of the first oil shock.

Figure 2 The Break in Australian GDP



Also of note is the fact that the Australian data does not show any evidence of a permanent pick-up in productivity and GDP growth since the mid-1990s. Whilst trend growth since 1995 has increased in Australia, from around 3 per cent per annum to over 4 per cent per annum (still well below the almost 5 per cent average growth rates of the 1960s), the spurt in economic growth has not been sustained into the new millenium. Average growth rates since 2000 have been, at best, similar to those experienced since 1971.

More formal evidence regarding the instability in the conditional moments of Australian GDP is provided in Table 2 Following Stock and Watson (2002) we conduct Andrews-Quandt type break tests on the coefficients of an AR model that allows either or both of the conditional mean and the conditional variance to break, possibly at different dates. The estimated model is of the form,

$$y_t = \alpha_t + \phi_t(L) y_{t-1} + \varepsilon_t$$

where

$$\alpha_t + \phi_t(L) = \begin{cases} \alpha_1 + \phi_1(L), & t \le \kappa, \\ \alpha_2 + \phi_2(L), & t > \kappa, \end{cases} \quad and \quad Var(\varepsilon_t) = \begin{cases} \sigma_1^2, & t \le \tau, \\ \sigma_2^2, & t > \tau, \end{cases}$$

where $\phi_1(L)$ and $\phi_2(L)$ are lag polynomials, and κ and τ are the break dates for the conditional mean and conditional variance respectively. The sup-Wald statistics (see Andrews (1993)) used to test the stability of the conditional mean are computed for all possible break dates in the central 70% of the sample. These test statistics both have highly non-standard distributions. Asymptotic p-values are computed using the methods provided in Hansen (1997).

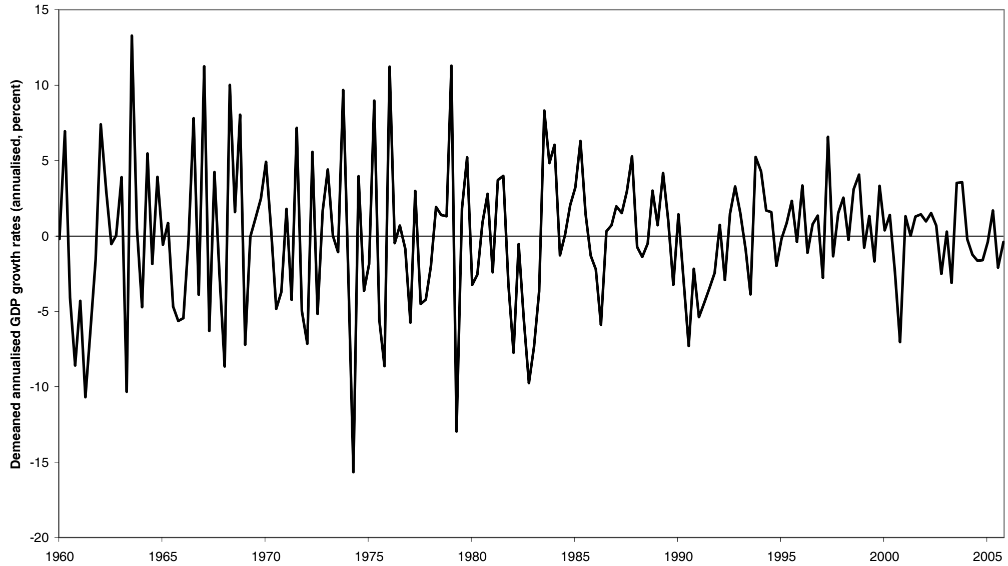
To test the stability of the conditional variance, the growth rate series was first demeaned, including allowance for any break in mean found for the series, and the sup-Wald test statistics calculated for the residuals from the estimated autoregression run on the demeaned data. For comparative purposes, results for stability of the conditional variance are also reported in Table 2 when the break in conditional mean found is ignored.

Table 2 Andrews-Quandt Tests for Structural Change

Real GDP Growth	Sup-Wald Test	P-Value	Break Date
Conditional Mean	**26.88**	**0.00**	**1971:03**
Conditional Std. Deviation	**45.89**	**0.00**	**1976:02**
Conditional Std. Deviation (Break in Mean : 1971:3)	**34.88**	**0.00**	**1982:01**

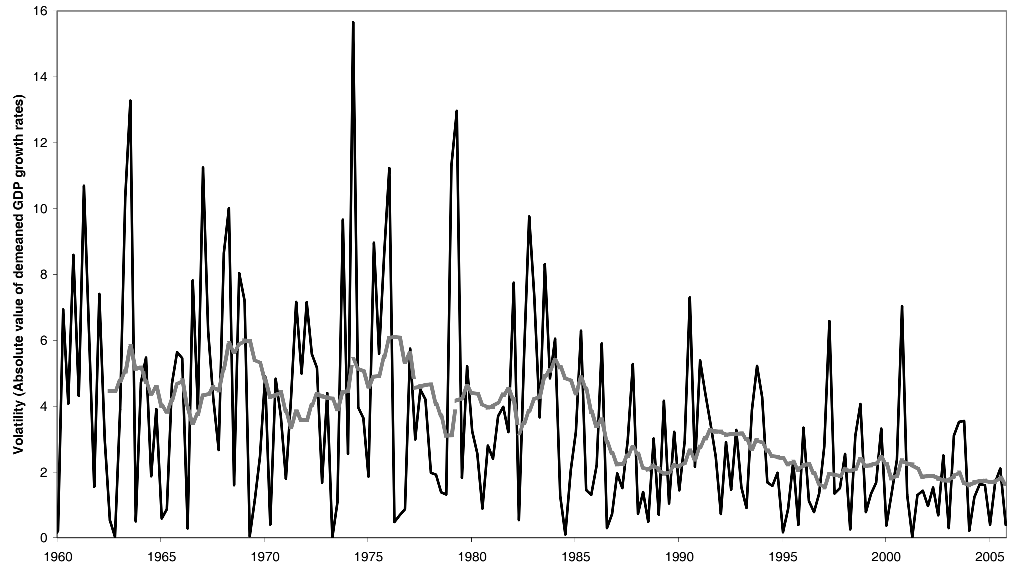
Table 2 suggests that there is strong evidence of a structural break in conditional mean in 1971:03 Australia, somewhat before the occurrence of the first oil price shock. Filtering the GDP growth rates on the basis of these results gave the demeaned growth rates as depicted in Figure 3.

Figure 3
Filtered real GDP Growth Rates
Australia Non-Constant Mean : Pre-1971:3 = 5.00, Post 1971:3 = 3.16



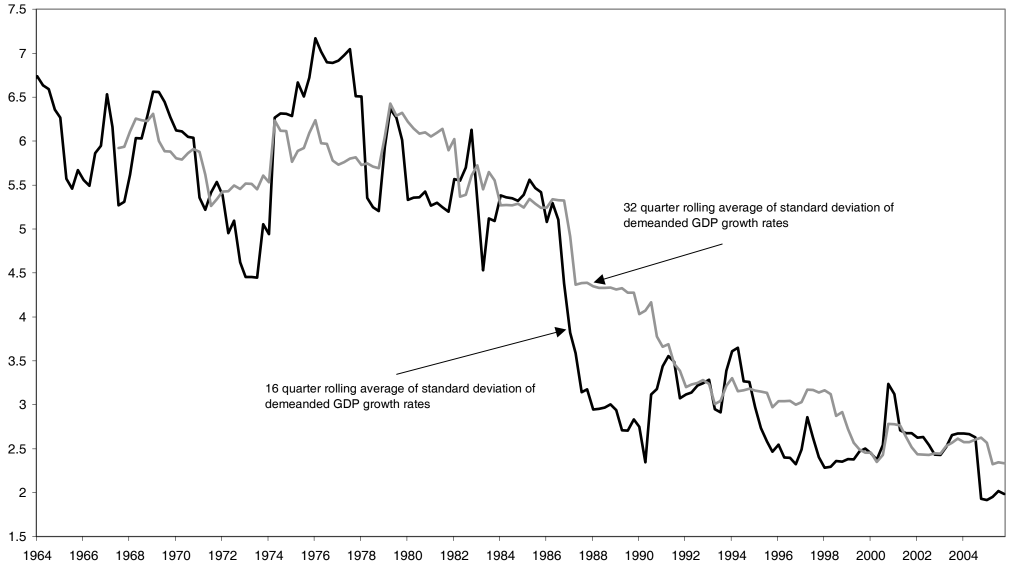
To provide further visual evidence of the decline in volatility, a time varying measure of volatility was generated as the absolute value of the demeaned annual growth rate as depicted in Figure 4 together with a simple 12th order moving average of the series. This visual evidence suggests a decline in volatility over time although the moving average smoother somewhat masks the existence of any major structural shifts at one or more specific points in time. Figure 5 further supports this visual evidence depicting rolling averages of the standard deviation of demeaned growth rates over 4 year and 8 year moving windows.

Figure 4
The Decline in Australian GDP Volatility



Source: ABS National Accounts in dX Database and authors calculations

Figure 5
Time-Varying Australian GDP Volatility



Source: ABS National Accounts in dX Database and authors calculations

Is the observed change in volatility in Australian GDP best modeled as a smooth long-run decline in volatility or is it more likely that what we have seen is a one-off major shift in the volatility level (and/or the mean of the GDP process)? If so, when did this change in volatility occur? For the US, authors such as Margaret McConnell and Gabriel Perez-Quiroz (2000) have used both simple and sophisticated statistical techniques to date the US structural change in output volatility at 1984:01, at the end of the rapid recovery period following the 1980s recession.

Can we further support the ocular evidence provided in Figures 4 and 5 with formal testing? To further investigate the issue, we estimate an AR(4) model of demeaned GDP growth and look for parameter instability using Nyblom's L test as described in Hansen (1992). Rejection of the null of stability occurs when we find large values of the relevant test statistic.

Results of the Nyblom test presented in Table 3 suggest we now cannot reject the stability of the parameters of the mean function (of filtered real GDP) over the sample but we can clearly reject the stability (constancy) of the residual variance. The joint stability of the parameters can be rejected at the 1 percent level (asymptotic 1 percent critical value is 2.12).[4]

[4] It should be noted that Hansen (1992) points out that if both the parameters of the mean function and the variance have shifted then the L test has only low power to detect the shift in the parameters of the mean function. Thus the test does not allow us to discount the possibility that the mean function has shifted with any degree of certainty although there is a clear indication that the variance is non-constant.

Table 3 : Nyblom's Test for Parameter Stability in Australian (Demeaned) GDP Growth

Specification : $\tilde{y}_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \tilde{y}_{t-i} + \varepsilon_t$

Parameter	L_c	5% Critical Value
α_0	0.04	0.47
α_1	0.34	0.47
α_2	0.11	0.47
α_3	0.09	0.47
α_4	0.09	0.47
ρ	0.05	0.47
σ^2	**2.22**	0.47
Joint L_c	**2.91**	1.90

Nyblom's test for parameter stability as described in Hansen (1992). L_c is the test statistic for a break point in each of the parameters listed in the first column. The null hypothesis is no break. Results obtained are robust to the exclusion of the time trend.

Of course the Nyblom test, as performed here, is only indicating that the variance is non-constant. Generating an estimate of the error variance as the squared residuals from an AR(4) model of the mean of filtered real GDP growth, and then estimating an AR(4) plus linear trend model of the conditional variance allows for the application of the Nyblom L test to the parameters of this conditional variance function. Results are presented in Table 4.

Table 4 : Nyblom's Test for Parameter Stability in the Conditional Variance of Demeaned Australian GDP Growth

Panel A : $\sigma^2{}_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \varepsilon_{t-i}^2 + \nu_t$

Parameter	L_c	5% Critical Value
α_0	**1.25**	0.47
α_1	0.22	0.47
α_2	0.21	0.47
α_3	**0.47**	0.47
α_4	0.33	0.47
σ^2	**0.70**	0.47
Joint L_c	**2.98**	1.68

Panel B : $\sigma^2{}_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \, \varepsilon_{t-i}^2 + \rho DT + v_t$

Parameter	**L_c**	**5% Critical Value**
α_0	0.05	0.47
α_1	0.03	0.47
α_2	0.05	0.47
α_3	0.04	0.47
α_4	0.04	0.47
ρ	0.06	0.47
σ^2	0.21	0.47
Joint L_c	1.72	1.86

Nyblom's test for parameter stability as described in Hansen (1992). L_c is the test statistic for a break point in each of the parameters listed in the first column. The null hypothesis is no break.

Now we see that the parameter instability concerning the variance suggested by the Nyblom tests performed on the mean function is well captured by the inclusion of a regime shift dummy in the conditional variance equation. There is no suggestion of any statistically significant parameter instability in any of the constant or autoregressive parameters of the conditional variance function, once the dummy term is included in this function. This is suggestive of a shift in the variance of real GDP growth over time, (a negative ρ suggesting a shift from high variance to low variance regime).

To further investigate the possible instability in the residual variance, the Andrews-Quandt structural break tests were applied to an AR(4) plus linear trend model of the estimated residual variance from the AR(4) model of the mean of the filtered GDP series. We saw from Table 2 that when a shift dummy is not included in the specification of the conditional variance equation, the structural break tests indicate clear statistical evidence of shifts in the variance of real GDP growth. However, once a regime shift is allowed for in the specification to capture the possible deterministic decline in volatility over the entire sample period, then we again see from the sup-Wald test results reported in Table 5 that, whilst the possible break date is now earlier according to the structural break test (1976:01 as opposed to 1982:01), the break is not significant.

Table 5 : Structural Break Tests with Unknown Break Point

Specification : $\sigma^2{}_t = \alpha_0 + \sum_{i=1}^{4} \alpha_i \, \varepsilon_{t-i}^2 + \rho DT + v_t$

	Andrews sup-Wald Test		**Break Date**
Coefficients	**Test**	**P-Value**	
All Coeffs	6.26	0.98	1976:01

Once again we seem to get the result that, independent of any short term business cycle volatility (ARCH or GARCH) effects, the general longer term path for the volatility in real GDP growth has been one that includes a major shift in regime. In this way these results strongly support the conclusions of authors such as Summers (2005), Smith and Summers (2002), and McConnell and Perez-Quiroz (2000).

4. Symmetric GARCH Models

In the previous section we provided evidence to show that the Australian economy exhibited both a permanent slowdown in the level of real GDP growth in 1971 and a decline in volatility in the early 1980s. This section now provides further evidence regarding the time-varying nature of volatility for Australia using GARCH models that account for these longer term changes in the first two moment of real GDP. The models uncover some further interesting features of the time-varying nature of output volatility, in particular that associated with the business cycle. In all models that follow, the dependent variable is demeaned real GDP growth, i.e. real GDP growth filtered to remove the non-constant mean, accounting for the estimated regime shift in 1971:03. Hence the focus is on the growth cycle characterisation of the business cycle rather than the classical cycle in levels.

Standard Box Jenkins ARIMA modeling of filtered mean GDP growth $\tilde{y}_t$ suggests that over the entire 1959:4-2004:4 sample, Australian GDP growth might best be modeled as a seasonal MA(4) process.

Table 6 : ARIMA Model of Australian Filtered GDP Growth : 1960-2005

$$y_t = \underset{(0.185)}{0.025} - \underset{(0.066^*)}{0.441}\, \varepsilon_{t-4}$$

Akaike Info Criterion = 5.81; Schwartz Criterion = 5.85
Jarque-Bera test for residual normality : J-B test = 4.69 (p-value = 0.01)
Ljung-Box Q-statistic for residual autocorrelation : Q(12) = 12.12 (p-value = 0.35)
Ljung-Box Q-statistic for squared residual autocorrelation : $Q^2(12)$ = 18.66 (p-value = 0.04)
LM test : ARCH(1) = 7.52 (p-value=0.01); LM test : ARCH(4) = 2.58 (p-value=0.03)
BDS (e, l) test : BDS(3, 1) = 4.77 (bootstrapped p-value = 0.002) ;
BDS(5,1.5) = 5.38 (bootstrapped p-value = 0.000)

Jarque-Bera tests indicate that the residuals from this simple linear ARIMA model exhibit nonnormality and BDS tests indicate some form of nonlinear dependence may be present in the residuals.[5] Ljung-Box tests indicate that whilst there is no significant autocorrelation remaining in the levels of the residuals, significant persistence remains in the squared residuals. Further analysis of the squared residuals from the ARIMA model, including LM tests for ARCH, indicates that significant uncaptured structure is present in the second moment of real GDP growth. To address these inadequacies with the simple ARIMA model of the mean a GARCH(1,1) model was estimated and the results are presented in Table 7.[6]

[5] BDS test (see Brock et al (1996) – a portmanteau test for time based dependence in a series. *e* represents the embedding dimension whilst *l* represents the distance between pairs of consecutive observations measured here as a multiple of the standard deviations of the series. Under the iid null, the BDS test statistic is asymptotically distributed as standard normal. Bootstrapped p-values were calculated using 5000 repetitions.

[6] Various specifications of ARCH in mean (ARCH-M) models were also estimated but in no case was it found that the volatility entered the mean equation with a significant coefficient.

Table 7 : GARCH(1,1) Model of Australian Filtered GDP Growth : 1960-2005

$$y_t = \underset{(0.169)}{0.102} - \underset{(0.066^*)}{0.379}\ \varepsilon_{t-4}$$

$$\sigma_t^2 = \underset{(0.136)}{-0.200} + \underset{(0.026^*)}{0.039}\ \varepsilon_{t-1}^2 + \underset{(0.029^*)}{0.965}\ \sigma_{t-1}^2$$

Akaike Info Criterion = 5.70.; Schwartz Criterion = 5.79
Jarque-Bera test for residual normality : J-B test = 0.67 (p-value = 0.72)
LM test : ARCH(1) = 1.49 (p-value=0.22); LM test : ARCH(4) = 1.36 (p-value=0.25)
BDS (e, l) test : BDS(3, 1) = 4.90 (bootstrapped p-value = 0.002) ;
BDS(5,1.5) = 5.64 (bootstrapped p-value = 0.000)

Note : figures in parentheses are Bollerslev-Wooldridge robust standard errors. A * in the parentheses indicates that the included variable is statistically significant at the 5% level i.e. a p-value of less than 0.05)

Whilst the GARCH(1,1) model appears to capture some of the additional dependence features of the data, allowing for periods of high volatility and low volatility in the series, it clearly does not adequately model the structural shift in output volatility, whether that be a gradual process or an abrupt shift from high to low volatility regime. Further modeling of the squared residuals indicates that in fact the best (lowest AIC and SBC, best residual diagnostics) specification of the residual variance includes a highly significant deterministic shift dummy in the variance term of an ARCH(1) specification as presented in Table 8.

Table 8 : Break-in-(G)ARCH Model of Australian Filtered GDP Growth : 1960-2005

$$y_t = \underset{(0.148^*)}{0.447} - \underset{(0.055^*)}{0.319}\ \varepsilon_{t-4}$$

$$\sigma_t^2 = \underset{(4.988^*)}{20.793} - \underset{(0.129^*)}{0.416}\ \varepsilon_{t-1}^2 - \underset{(4.991^*)}{15.176}\ DT$$

Akaike Info Criterion = 5.65.; Schwartz Criterion = 5.74
Jarque-Bera test for residual normality : J-B test = 1.18 (p-value = 0.55)
LM test : ARCH(1) = 0.017 (p-value=0.89); LM test : ARCH(4) = 0.176 (p-value=0.96)
BDS (e, l) test : BDS(3, 1) = 4.96 (bootstrapped p-value = 0.001) ;
BDS(5,1.5) = 5.58 (bootstrapped p-value = 0.000)

Note : figures in parentheses are Bollerslev-Wooldridge robust standard errors. A * in the parentheses indicates that the included variable is statistically significant at the 5% level i.e. a p-value of less than 0.05)

Given the significance of the deterministic shift dummy, it is included in all the models in the remainder of the analysis to capture the marked decline in volatility in Australian output over the sample period whilst also trying to capture any other time-varying dynamics of output volatility. Interestingly, the BDS tests on the residuals of the model presented in Table 8 indicate that some form of nonlinear dependence persists and is not being fully captured by the linear ARIMA model with (G)ARCH errors. This is further investigated through the estimation of additional models that attempt to capture various nonlinearities in the output process that might be of significant economic interest.

5. Asymmetries

5.1 TARCH

Interestingly, there is some evidence of asymmetry in the ARCH process (a leverage effect) when the residuals from the mean specification of the previous section are modeled as either threshold ARCH (TARCH) process (as introduced independently by Zakoïan (1994) and Glosten, Jaganathan, and Runkle (1993)), or an exponential GARCH (EGARCH) process as proposed by Nelson (1991).

We can write a simple TARCH process for Australian filtered GDP as

$$y_t = \beta_0 + \varepsilon_t + \theta_1 \varepsilon_{t-4}$$

with conditional variance given by $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + +\delta\sigma_{t-1}^2 + \gamma\varepsilon_{t-1}^2 d_{t-1} + \rho DT$

where $d_{t-1} = 1$ if $\varepsilon_t < 0$, and 0 otherwise.

Results from the estimation of the best-fitting TARCH model are presented in Table 9.

Table 9 : TARCH Model of Australian GDP Growth : 1960-2005

$$y_t = \underset{(0.148)}{0.3571} - \underset{(0.052^*)}{0.345}\ \varepsilon_{t-4}$$

$$\sigma_t^2 = \underset{(4.282^*)}{21.785} + \underset{(0.105)}{0.044}\ \varepsilon_{t-1}^2 + \underset{(0.235^*)}{0.697}\ \varepsilon_{t-1}^2 d_{t-1} - \underset{(4.299^*)}{16.503}\,DT$$

Akaike Info Criterion = 5.59.; Schwartz Criterion = 5.72
Jarque-Bera test for residual normality : J-B test = 1.11 (p-value = 0.57)
LM test : ARCH(1) = 0.034 (p-value=0.85); LM test : ARCH(4) = 0.055 (p-value=0.70)
BDS (e, l) test : BDS(3, 1) = 4.89 (bootstrapped p-value = 0.002) ;
BDS(5,1.5) = 5.33 (bootstrapped p-value = 0.001)

Note : figures in parentheses are Bollerslev-Wooldridge robust standard errors. A * in the parentheses indicates that the included variable is statistically significant at the 5% level i.e. a p-value of less than 0.05)

The shift dummy remains negative and highly significant. The positive coefficient on the asymmetry term suggests that negative shocks to real GDP growth create significant increases in its volatility compared to positive shocks – *the news impact is asymmetric*. These results are robust to the inclusion of additional AR lags or lags of a GARCH term in the GARCH process.[7] An EGARCH specification for modeling volatility gives very similar results (not shown) with similar implications – a significant regime shift in volatility plus a significant *leverage effect*.

5.2 (G)ARCH-Y

Another approach to investigating whether fluctuations in real GDP volatility are associated with the level of GDP growth is to estimate a (G)ARCH-Y model in which the level of real

[7] Once again, various specifications of ARCH in mean (ARCH-M) models were also estimated but in no case was it found that the volatility entered the mean equation with a significant coefficient.

GDP growth is included in the specification of the variance equation, together with regime shift term. This allows us to draw inference as to whether higher real GDP growth is associated with lower variance in real GDP growth and vice-versa i.e. *whether 'good times' are associated with both high growth and increased economic stability.* This specification is similar to that used by Peel and Speight (1998) for various business cycle indicators for the UK and the US, although they did not consider real GDP.

We can write a simple GARCH-Y process for Australian real GDP growth y_t as

$$y_t = \beta_0 + \varepsilon_t + \theta_1 \varepsilon_{t-4}$$

with conditional variance given by $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \delta\sigma_{t-1}^2 + \rho\, DT + \zeta\, y_{t-1}$

Note that only one lag of GDP growth is included in the variance equation for parsimony, although simple Wald tests and consideration of the AIC and SBC did indicate that this was appropriate, and the trend term was also maintained.

Table 10 : (G)ARCH-Y Model of Australian GDP Growth : 1960-2004

$$y_t = \underset{(0.151)}{0.268} - \underset{(0.061^*)}{0.344}\, \varepsilon_{t-4}$$

$$\sigma_t^2 = \underset{(4.030^*)}{22.360} + \underset{(0.089)}{0.234}\, \varepsilon_{t-1}^2 - \underset{(0.398^*)}{15.111} DT - \underset{(0.457^*)}{0.994}\, y_{t-1}$$

Akaike Info Criterion = 5.61.; Schwartz Criterion = 5.72
Jarque-Bera test for residual normality : J-B test = 1.12 (p-value = 0.57)
LM test : ARCH(1) = 0.201 (p-value=0.65); LM test : ARCH(4) = 0.206 (p-value=0.93)

Note : figures in parentheses are Bollerslev-Wooldridge robust standard errors. A * in the parentheses indicates that the included variable is statistically significant at the 5% level i.e. a p-value of less than 0.05)

The results indicate that the shift dummy remains highly significant and that the lagged GDP growth rate enters the variance equation significantly and with a negative coefficient. It appears that *higher GDP growth rates are associated with significant decreases in volatility.* This result seems to be somewhat at odds with the basic evidence presented earlier, which suggested for example that the 1959-1970 period was one of very rapid growth and high volatility in quarterly real GDP growth rates. The results presented here illustrate the importance of capturing both the structural break in average GDP growth as well as the significant decline in volatility in the sample (through the inclusion of a deterministic dummy in the conditional variance function) when trying to also capture the potential short term business cycle relationship between growth rates and volatility.

It is important to note that in their paper, Peel and Speight (1998) argue that such a GARCH-Y specification actually captures possible business cycle asymmetries in the conditional variance. They argue that such asymmetries are identified by the sign of the coefficient on the lagged growth rate (or sum of the signs of any significant coefficients on lagged growth rates if more than one lag is included in the variance equation). In fact, such a specification is *not* able to identify any asymmetries in this sort of growth-cycle specification. This basic GARCH-Y model only captures whether the conditional variance is increasing or decreasing significantly with the level of real GDP growth – as modeled, the conditional variance is a linear function of real GDP growth rates. In order to examine whether the actual *phases* of the business cycle matter for GDP volatility one needs to identify / date the phases of interest and then include such information in a *nonlinear* specification of the variance equation.

5.3 Cyclical Asymmetries

To further investigate the possibility of such cyclical asymmetries, firstly break up the demeaned GDP growth series, $\tilde{y}_t$, into two separate series as follows:

$$\text{Neg} = \begin{cases} \tilde{y}_t & if \quad \tilde{y}_t \leq 0 \\ 0 & otherwise \end{cases}$$

$$\text{Pos} = \begin{cases} \tilde{y}_t & if \quad \tilde{y}_t > 0 \\ 0 & otherwise \end{cases}$$

These two variables are then included in the variance equation of a simple Break-in-GARCH model instead of the level of GDP growth series.[8] Consideration of the signs and magnitudes of the coefficients on each of the two series together with Wald tests of individual significance of each of the series and of the equality between the coefficients on each of the series provides an indication of whether such cyclical effects are present and whether they are asymmetric over phases where GDP growth is positive as opposed to negative. Since we have removed the non-constant mean from the real growth rates then defining the threshold between phases as being zero we are actually investigating whether it is 'above average growth' that matters for generating lower volatility (or alternatively 'below average growth' that matters for generating higher volatility) where we are accounting for the fact that average growth was significantly higher in the early part of the sample.

An alternative definition of the two cyclical phases is to use the simple 'at least two quarters of negative growth in GDP growth' for defining a classical type recession phase (Neg2). In this case, quarters of negative GDP growth that are neither preceded or followed by another quarter of negative growth are identified as being recession periods whilst all other periods are defined as being in the normal expansion phases (Pos2).

Finally, a simple dummy variable approach is used to specify the classical phases of the cycle using the classical dates for Australia specified by the Economic Cycle Research Institute (ECRI). A dummy is created whose value is zero for expansion phases and 1 for recession periods and this variable is then incorporated into the variance equation.

Estimation of such augmented (G)ARCH-Y models suggests that there is significant evidence in favour of asymmetry in volatility across phases of the cycle. Periods of low growth or periods defined as classical recession phases appear to be characterised by quantitatively much higher volatility and the statistical evidence suggests that the Neg, Neg2 and ECRI variables are statistically significant at the 5% level. Expansion phases of the cycle,

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[8] Again, since no evidence was found of significant GARCH terms in the models, an ARCH(1) specification was used in each case.

or high growth periods, are not characterised by a statistically significant decline in volatility relative to average.

Table 11 : Asymmetric (G)ARCH-CYC Models of Australian GDP Growth : 1960-2005

(1)	$y_t = \underset{(0.149^*)}{0.331} - \underset{(0.053^*)}{0.351}\,\varepsilon_{t-4}$ $\sigma_t^2 = \underset{(4.372^*)}{20.496} + \underset{(0.097)}{0.317}\,\varepsilon_{t-1}^2 - \underset{(4.181^*)}{14.135}\,DT - \underset{(0.538)}{0.669}\,Pos_{t-1} - \underset{(0.494^*)}{1.056}\,Neg_{t-1}$ Wald Test : $Pos_{t-1} = 0$ $(P-value = 0.216)$ Wald Test : $Neg_{t-1} = 0$ $(P-value = 0.023)$ Wald Test : $Pos_{t-1} = Neg_{t-1}$ $(P-value = 0.134)$
(2)	$y_t = \underset{(0.157)}{0.291} - \underset{(0.049^*)}{0.382}\,\varepsilon_{t-4}$ $\sigma_t^2 = \underset{(4.900^*)}{28.370} + \underset{(0.089)}{0.108}\,\varepsilon_{t-1}^2 - \underset{(4.446^*)}{19.575}\,DT - \underset{(0.346)}{0.662}\,Pos2_{t-1} - \underset{(4.969^*)}{11.049}\,Neg2_{t-1}$ Wald Test : $Pos2_{t-1} = 0$ $(P-value = 0.09)$ Wald Test : $Neg2_{t-1} = 0$ $(P-value = 0.026)$ Wald Test : $Pos2_{t-1} = Neg2_{t-1}$ $(P-value = 0.040)$
(3)	$y_t = \underset{(0.162^*)}{0.479} - \underset{(0.055^*)}{0.361}\,\varepsilon_{t-4}$ $\sigma_t^2 = \underset{(4.763^*)}{24.105} + \underset{(0.093)}{0.168}\,\varepsilon_{t-1}^2 - \underset{(4.753^*)}{18.598}\,DT + \underset{(10.417^*)}{27.743}\,ECRI_t$ Wald Test : $ECRI_t = 0$ $(P-value = 0.009)$

Note : figures in parentheses are Bollerslev-Wooldridge robust standard errors. A * in the parentheses indicates that the included variable is statistically significant at the 5% level i.e. a p-value of less than 0.05)

The key evidence provided in this section concerns the apparent robustness of the negative, and statistically significant regime shift in volatility in the middle of the sample period. There is also some evidence of significant cyclical asymmetries in the volatility process from TARCH, (G)ARCH-Y and (G)ARCH-CYC models. Significant leverage effects in volatility are found - *negative shocks to real GDP growth create significant increases in its volatility compared to positive shocks*. Periods of low real GDP growth and classical recessions are associated with significantly higher volatility. There is no evidence in favour of expansions or high growth periods as being periods of significantly higher or lower volatility once the shift in output volatility during the sample period is accounted for. Again, these are statistically significant characteristics of the GDP process that should be included in any discussion of ‘stylised facts’ concerning the Australian economy.

6. What is the source of the decline in output volatility?

6.1 Growth contributions

The previous section provided an analysis of the cyclical characteristics of the second moment of the output process for Australia, whilst attempting to capture the underlying structural shift in volatility that took place in 1982. Having done this, we can now ask what might be the key underlying economic factors driving this move towards a low volatility environment? What has changed? Several authors have proposed a variety of possible answers, including better (monetary) policy, structural changes due to technological innovations and regulatory shifts, diminished reliance on volatile oil sources, increased integration of goods and financial markets (globalisation) and even 'good luck'! A recent survey of evidence concerning these potential factors is provided in Cecchetti, Flores-Lagunes and Krause (2005).

As a first step in trying to distinguish between these different explanations, the simple approach of McConnell and Perez-Quiroz (2000) is followed. The components that make up GDP are examined to see how their volatility has changed across the two sub-periods suggested by the Andrews-Quandt break tests in section 2. Of course, in order to assess how central each of the volatility changes in each of the components of GDP has been, we need to incorporate information regarding the 'importance' of each component of GDP. To do this, the volatility of each component's growth contribution to real GDP growth is examined. The growth contribution is roughly the real growth rate of the component multiplied by its share in total GDP. Growth contributions provide a convenient measure for adding up the components of GDP growth, as they take into account the size of each component relative to GDP. A simple standard deviation measure of the volatility of each component's growth contribution is used to assess each component's contribution towards the overall decline in GDP. The results of calculating these volatility measures are presented in Table12.

Table 12: Volatility of GDP Components' Growth Contributions

	Standard Deviation			
	(a) 1959:04–1982:01	(b) 1982:02–2005:4	Difference	Ratio (b)/(a) (per cent)
Household Consumption	0.546	0.375	–0.171	68.7
Consumption of Durable Goods	0.136	0.158	+0.22	116.2
Government Consumption	0.416	0.345	–0.071	82.9
Government Investment	0.280	0.426	+0.146	152.1
Inventory Investment	0.942	0.729	–0.213	77.4
Business Investment	0.502	0.782	+0.280	155.8
Dwelling Investment	0.233	0.313	+0.080	134.3
Exports	0.536	0.512	–0.024	95.5
Imports	0.581	0.531	–0.049	91.4

Source: ABS National Accounts in dX Database and author's calculations

The calculations show that quantitatively, the greatest contributor to the overall reduction in GDP volatility is inventory investment. This result is similar to that found for the US and is quite striking given that this component accounts for less than 0.5 per cent of total GDP. Inventory investment has typically been the most volatile component of GDP over time and has contributed the most to GDP growth volatility, although interestingly business fixed investment in Australia has now overtaken it as the largest contributor.

What explains the large decline in the volatility of this sector of the economy in recent times? Part of the story at least seems to be that large-scale structural changes in inventory management were implemented beginning in the 1980s, driven to some degree by new technology. Computer-based 'just-in-time' inventory management and ordering systems helped keep inventories more in line with the state of demand and also drove a marked decline in the average level of inventory stocks.

The other major component driving increased stability is consumer spending. This is less surprising than the inventory investment effect since consumer spending makes up such a large share of GDP and even modest declines in consumption volatilities are likely to have large impacts on the volatility of GDP. Of course, it could be that the decline in volatility in most other sectors, and in the aggregate, serve to cause the decline in consumption volatility also.

As can be seen from Table 12, the decline in the volatility of exports and imports contribute far less to the overall decline in GDP volatility than might have been expected if one were to believe that increased trade and openness were important factors moderating the business cycle. Also, the large increases in both business and dwelling investment volatility are important offsetting factors on an otherwise positive story and it is clear that explaining the volatility of investment (other than inventory investment) is important in understanding the continued volatility in the Australian economy.

6.2 Growth variability over the business cycle

Is it the case that the measured decline in output volatility is due to that fact that Australia, like the US, has only experienced one fairly mild recession over the period since 1984 (mild in terms of depth but quite severe in terms of duration and unusual in the sluggishness of its post-recession recovery phase), whereas it experienced four other classical recessions in the 1960s, 70s and early 1980s? If it is the lack of recessions that is the story, then we might expect that GDP growth volatility would be similar in the 1982:01–2005:4 period as it was in the earlier expansion periods outside of recession. One simple way of determining if this is actually the case is to eliminate recessions from the analysis and re-do the analysis for GDP growth contributions for the two sample periods. Using the classical business cycle dates defined by the Economic Cycle Research Institute, the necessary calculations were performed and are given in Table 13.

The analysis shows that removing recessions does not change the relative contributions of the different GDP components to overall volatility decline a great deal. Inventory investment remains an important factor driving the decline in GDP volatility, whilst exports and imports become much less important than they were when recessions were included. In fact imports now serve to increase volatility in GDP growth, although their effect is not quantitatively large. Other forms of private investment, including dwelling investment, show significant increases in volatility over the expansions of the later period. Clearly, strong economic growth since the mid-1980s has been associated with major booms and busts in the Australian housing market, but business investment has also increased its variability significantly. Interestingly, government consumption expenditure has been a force for increased economic stability in the expansion phases of the last twenty years, although this is largely offset by the increased instability due to government investment expenditures.

Table 13: Volatility of GDP Components' Growth Contributions during Expansions

	Standard Deviation		
	1959:4–19821:01	**1982:02–2005:4**	**Difference**
Household Consumption	0.516	0.341	–0.175
Consumption of Durables	0.133	0.153	+0.020
Government Consumption	0.675	0.478	-0.197
Government Investment	0.290	0.410	+0.120
Inventory Investment	0.875	0.721	–0.154
Business Fixed Investment	0.465	0.801	+0.336
Dwelling Investment	0.212	0.312	+0.101
Exports	0.519	0.516	–0.003
Imports	0.491	0.512	+0.021

Source: ABS National Accounts in dX Database and author's calculations

6.3. Related Factors

The previous two sub-sections examined the contribution of various components of GDP towards the decline in volatility of overall GDP growth. Of course we can also examine the time-varying nature of the volatility in other economic factors that may be associated with the overall decline in output volatility, including supply-side factors. These include external factors such as the terms of trade, the total output of our major trading partners, the world prices of major exports such as mining and agricultural products and the general commodity price index, the world price of oil, and domestic factors such as money growth rates and the growth in nominal and real wages. Standard deviation of growth rates measures are given for each of these factors over the same sub-periods as for the previous sections in Table 14.

Table 14: Volatility of other Economic Factors

	Standard Deviation		
	(a) 1959:04–1982:01	**(b) 1982:02–2005:4**	**Ratio (b)/(a) (per cent)**
GDP of Major Trading Partners	0.74	0.56	76.45
Terms of Trade	3.87	1.90	49.16
Commodity Price Index	5.30	3.34	63.15
World Price of Agricultural Goods	5.29	5.28	99.85
World Price of Mining goods	5.30	3.14	59.26
World price of petroleum	14.06	13.20	93.91
Money growth (M3)	1.50	1.42	94.68
Real money growth (M3)	1.80	1.39	77.30
Average nominal wage rate	1.84	1.10	59.78
Average real wage rate	1.67	0.97	58.01

Source: RBA Bulletin and ABS treasury Model databases in dX Database and author's calculations

As Table 14 illustrates, the decline in Australia's output volatility has been accompanied by a similar decline in the volatility of its major trading partners. The terms of trade, the world commodity price index and the world price of mining goods have also shown significant decreases in volatility. World agricultural prices and oil prices have not stabilised substantially over the two sub-periods. However, these two components of output have shown some decline in their share in trade and output over time which might magnify any contribution such factors might have in aiding economic stability. The volatility of money growth can be seen as a crude indicator of the influence of monetary policy on economic stability, although uncovering the full, potentially endogenous, interaction between policy and stability would require much more sophisticated analysis than mere statistical measurement such as that presented here (see Cecchetti, Flores-Lagunes and Krause (2005) for analysis and evidence). However, it is interesting to document that a significant decline in the volatility of real money growth occurred post break. Finally, it is interesting to note the substantial decline in both nominal and real wage variability that has occurred since the early 1980s. Greater stability in labour input costs might also be a contributing factor to improved business activity, general macroeconomic stability and in particular, the stability of output.

Conclusions

This paper has investigated the decline in volatility of real GDP growth in Australia for the period 1959 to 2005. As in the US, real GDP growth in Australia appears to have become significantly more stable over time. A variety of estimation and test procedures were employed to identify the nature and timing of this apparent 'great moderation' in the Australian context, identifying an abrupt one-off regime change from high to low volatility in 1982, slightly earlier than the date that has been proposed for the US economy.[9] Results suggest the increased stability is adequately captured through the incorporation of a deterministic shift dummy in the conditional variance equation of an ARMA-ARCH model of real GDP growth.

Besides finding evidence towards a persistent shift towards lower volatility, we also investigate other shorter term and cyclical issues regarding variability in Australian output. In common with earlier studies for various other countries we also find evidence of significant ARCH / GARCH effects in the conditional volatility. Estimation of various (trend in-) ARCH models suggests that there is evidence of conditional volatility asymmetry (leverage effects), with negative shocks imparting greater volatility than positive shocks of similar magnitude. This is consistent with recent evidence for US and Canada.[10] Estimation of a (G)ARCH-Y model, in which the level of real GDP growth is included linearly as an explanatory regressor in the variance function, suggests that higher rates of real GDP growth are associated with significantly lower volatility. Estimation of threshold type (G)ARCH-CYC models suggest evidence in favour of asymmetry in volatility across phases of the cycle. Periods of low growth or periods defined as classical recession phases appear to be characterised by quantitatively much higher volatility. Expansion phases of the cycle, or high growth periods, are not characterised by a statistically significant decline in volatility.

The final section of the paper examines some of the potential causes of the decline in volatility that has occurred over the sample period. As a simple first step in trying to distinguish between the different explanations, the approach of McConnell and Perez-Quiroz

[9] See Summers (2005) and McConnell and Perez-Quiroz (2000).
[10] See Ho and Tsui 2003.

(2000) is utilized to examine the volatility of various key expenditure component's growth contribution to real GDP growth and see how their volatility has changed across the two sub-periods as suggested by the Andrews-Quandt break tests in section 2. The calculations show that quantitatively, the greatest contributor to the overall reduction in GDP volatility is inventory investment. The other major component driving increased stability is consumer spending. Notably, the decline in the volatility of exports and imports over time contributes far less to the overall decline in GDP volatility than might have been expected if one were to believe that increased trade and openness were important factors moderating the business cycle. Similar simple analysis shows that removing recessions does not change the relative contributions of the different GDP components to overall volatility decline a great deal.

Finally, an examination of the time-varying nature of the volatility in other economic factors that may be associated with the overall decline in output volatility is carried out, including supply-side factors. The decline in Australia's output volatility has clearly also been accompanied by a similar decline in the volatility of its major trading partners and the terms of trade, the world commodity price index and the world price of mining goods have also shown significant decreases in volatility. It is interesting to document that a significant decline in the volatility of real money growth occurred post break and also to note the substantial decline in both nominal and real wage variability that has occurred since the early 1980s. Greater stability in labour input costs might also be a contributing factor to improved business activity and stability of output.

Overall it must be concluded that the so-called 'Great Moderation' in macroeconomic instability across many OECD countries, and clearly documented here for Australia, is a result of a myriad of economic, institutional and policymaking changes. Some of these changes are country-specific but most of these are likely due to increased economic integration, both through trade and globalization, but also through a common improvement in economic institutions, economic and social infrastructure and economic management.

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