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Don Harding

The University of Melbourne

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Abstract

In this paper I address the following questions.

- Has the business cycle become longer and shallower? And why?
- How stabilizing is monetary policy.

In answering these questions I summarize recent research undertaken by Adrian Pagan and myself that formalizes the procedures developed by Burns and Mitchell at the NBER. Defence of our position goes beyond continuity with the past and is based on the view that the way in which these investigators defined the business cycle is a very natural one that connects with the way policy makers and commentators discuss the cycle.

After discussing how to extract cyclical information my attention then turns to describing the features of the Australian business cycle. Here I employ recently constructed data on annual GDP that goes back to 1861. The recurrent pattern of peaks and troughs in this annual data marks out recessions that are somewhat more severe than that seen in quarterly data. I find little evidence that these major contractions are shorter in the second half of the 20th century than they were in the second half of the 19th century. Major expansions in the late 20th century were, however, longer than for any previous period. I find that the volatility of annual GDP growth rose markedly in the first half of the 20th century but declined to an all time low in the second half of that century. However, the decline in volatility between the late 19th and late 20th centuries is not very marked.

After examining the quarterly data available from 1959.3 to 2001.4 I find little evidence that contractions are shorter but there is some very weak evidence that the amplitude of these contractions has moderated.

The apparent decline in volatility of Australian GDP is shown to be explained by two statistical factors viz there is some residual seasonality in GDP which seems to be more pronounced in the 1960 and 70s and the ABS has reduced the extent of measurement error in GDP. After accounting for these no long run trend is discernable in volatility.

Key Words: Business cycle; growth cycle, turning points, monetary policy.

JEL Code C22, C53, E32

*Melbourne Institute of Applied Economic and Social Research, The University of Melbourne, Melbourne 3010, Australia. Email d.harding@unimelb.edu.au.

1 Introduction

My brief is to address two longer term issues related to the Australian business cycle.¹ The specific questions that I was asked to address are:

1. Has the business cycle become longer and shallower. And Why?
2. How stabilizing is monetary policy?

There are a number of approaches that one could take when addressing these questions. I have chosen to use non-parametric techniques that have been developed in a series of recent papers; see Harding and Pagan (2000a,b,2001a,b,2002a,b). There are three main reasons for using these techniques. First they do not rely on a particular parametric model of the business cycle and therefore provide a degree of robustness in the answers given. Second, the particular techniques chosen fit with the the popular language for discussing business cycles thereby making the analysis accessible to a broader audience. Third, the techniques are robust to variations in data quality. The latter point is particularly important as I have chosen to examine the Australian business cycle over a long time horizon 1861 to 2000/01; there are marked variations in data quality over this period. This latter choice reflects the fact that the economic events of interest here viz recessions, deflations and inflations are rare; discussions of these events that focus on short spans of data can be misleading.

Common usage associates recessions with a sustained decline in economic activity. The beginning and ends of such recession events are marked, respectively, by a local peak and trough in aggregate economic activity. Such extreme macroeconomic events are times when policy makers and policy institutions are put under greater strain than is usual. It is of interest to understand how both perform in these testing situations. Such evaluations are of considerably more relevance than evaluations of the average performance of policy makers. Policy interest also focuses on how frequent are such extreme macroeconomic events. And, if changes in the frequency of such events are observed, one wants to know whether those changes are attributable to policy or to factors outside of the control of policy. A third reason for being interested in extreme events is that such events place greater strain on statistical models and economic theories than do run-of-the-mill events and thus provide a useful testing ground for such models and theories.²

Both of the questions addressed in this paper require investigation of a reasonably technical nature if they are to be answered in anything but a cursory way. Section 2 provides the necessary background technical material presented in a way that, hopefully, makes it accessible to a broad spectrum of readers, places the techniques in their historical context and explains why the approach

¹My understanding is that that the second paper in this session by Dr Peter Summers will address the short term issue of the likely prospects for the economy in the next two years.

²See Harding and Pagan (2000, 2002) for examples of how these techniques discussed here can be used to test various models of the business cycle.

taken in this paper was adopted. Readers interested in more technical material may wish to consult the papers cited in Section 2.

The question of whether the business cycle has become longer and shallower is addressed in section 3 using annual data over the period 1861 to 2000/01. Annual data has the advantage that it is available over a long period of time and thus allows the current business cycle to be viewed in its historical perspective. The disadvantage of annual data is that it only picks up major recessions. Thus section 3 also locates turning points in quarterly GDP data available from 1959.3 to 2001.4 to address the question of how has the business cycle changed over the past 40 years.

The main findings in section 3 are firstly that the Australian business cycle in the second half of the 20th century was remarkably similar to the business cycle in the last half of the 19th century — The outlier seems to have been the first half of the 20th century — and secondly that there is at best weak evidence that the business cycle has moderated in the past 40 years. This latter conclusion will seem astonishing to many people as inspection of a graph of the quarterly growth rate of GDP suggests that there has been a marked decline in volatility. Section 4 sets out to investigate what it is that accounts for the apparent contradiction between the findings of section 3 and the graph just cited. Two lines of inquiry are taken the first is that there is some residual seasonality in the ABS's "seasonally adjusted" measure of GDP. This residual seasonality is more apparent in the 1960s and 1970s than in the latter period and accounts for some of the apparent decline in volatility. The other factor investigated is that the ABS has improved its practices over time and this has resulted in a reduction in measurement error. It is therefore necessary to investigate how much of the apparent decline in volatility is attributable to these factors.

Section 5 turns to the question of what is the nature of the process generating annual GDP and the related question of how predictable are major turning points that mark the beginning and end of major recessions.

Conclusions are presented in section 6 and lessons about the business cycle today are drawn from the discussion of earlier historical episodes.

2 Methods for measuring business cycles

Burns and Mitchell (1946) sought to locate their classic work *Measuring Business Cycles* within the broader scientific notion of cycles and therefore defined a business cycle via turning points in the *level* of economic activity.³ At the time research for *Measuring Business Cycles* was initiated the concept of aggregate economic activity was reasonably well developed and associated with GDP. But, a time series for GDP adequate for studying business cycles had not yet been constructed. Thus researchers at the the National Bureau of Economic Research (NBER) set out, under the direction of Wesley Mitchell, to measure the business cycle in three ways,

³The scientific literature defines a cycle in terms of turning points in an ordered series; see Clemments (1923).

- Willard Thorpe (1926) used written accounts of economic activity to compile *Business Annals*;
- Simon Kuznets set out to measure gross domestic product; and
- Wesley Mitchell, Simon Kuznets and Arthur Burns set out to identify series that are coincident with the business cycle. They located turning points in each of these series using rules like those set out in section 2.1 below. The business cycle was measured by aggregating the turning points in those specific cycles. The method of aggregation is discussed in section 2.2 where I compare the business cycle in GDP with the business cycle obtained by aggregating turning points

GDP is a natural measure of the level of economic activity and thus in this paper I will seek to measure the business cycle in terms of local maxima and minima of the sample path of GDP.⁴ In some circles this remains a controversial decision and it is useful to explain why, and to put forward the reasons for the position taken in this paper.⁵

Burns and Mitchell explain their motivation for proceeding as they did in *Measuring Business Cycles* as follows, first they focus on the conceptual ideal,

“aggregate activity can be given a definite meaning and made conceptually measurable by identifying it with gross national product at current prices” (Burns and Mitchell 1946 p72)

Then, they discuss the practicalities of proceeding in that way,

Unfortunately, no satisfactory series of any of these types is available by months or quarters for periods approximating those we seek to cover. Estimates of the value of the gross or net national product on a monthly or quarterly basis are still in an experimental stage. The Department of Commerce estimates of total income payments by months go back only to 1929. Recently, Harold Barger has prepared quarterly estimates of net and gross national product in the United States back to 1921. For Great Britain, Colin Clark has devised quarterly figures on national income since 1929. These statistical efforts represent an important step forward in the measurement of ‘national income’ by short time units and bear considerable promise for the future. But as yet they rest heavily on estimates eked out from small samples or purely mathematical interpolations which leave considerable margins of uncertainty in the final result. Burns and Mitchell (1946 p. 73)

⁴It is convenient to work with the turning points in $y_t = \ln(GDP_t)$ rather than GDP_t . Since these turning points are identical the transformation loses no information.

⁵See Banerjee and Layton (2001) who complain about using GDP to measure the business cycle and also the earlier exchange between Cloos (1963a,b) and Zarnovitz (1963a,b).

Today there is little warrant for considering GDP as experimental — the US Commerce Department nominated GDP as its innovation of the 20th century — almost all countries have statistical offices that assemble national accounts and GDP is generally accepted as the most comprehensive measure of economic activity available. Thus its was natural for Pagan and I to build our work on the business cycle around GDP. Viewed against the practices of the NBER our approach might be regarded as new or controversial. But viewed against their stated preference, our approach represents a return to what Burns and Mitchell said they would do if the suitable data on GDP had been available.

It worth expanding on this a little more to note that Burns and Mitchell expressed a preference for GDP in current prices. The main reason for this was that during most of the 19th century and much of the first third of the 20th century prices were relatively stable and thus nominal GDP provided a sensitive measure of economic activity. However, the price inflation after WWI and throughout most of the second half of the 20th century meant that nominal GDP was not a reliable measure of aggregate economic activity. For this one needs to subtract of the effect of price inflation to obtain real GDP the measure used in this paper.

For some purposes it is desirable to focus on cyclical information in series from which a trend is removed this leads to the concepts of the growth cycle and the cycle in the output gap both of which are discussed briefly in section 2.3.

The approach taken in this paper is not the only one that can be taken when studying the the business cycle. Sections 2.4 and 2.5 explore two alternative approaches. Section 2.4 discusses the regime switching approach which is an alternative method of segmenting the data into periods of expansion and contraction. Section 2.5 discusses the so called unseen cycle and the use of spectral analysis to study the business cycle. This latter section also discusses the validity of the hypothesis that economic fluctuations are periodic.

2.1 Rules for locating turning points

The familiar calculus rule that $\frac{dy}{dt} < (>)0$ to the right (left) of a local peak (trough) provides a starting point for locating turning points in a series. Economic series are recorded at discrete intervals and typically are not continuous functions of time thus, discrete analogs of the calculus rule are required. Visualizing a peak in a series leads one to the idea that a local peak in y_t occurs at time t if y_t exceeds values y_s for $t - k < s < t$ and $t + k > s > t$, where k delineates some symmetric window in time around t . A local trough can be defined in a similar way.

The frequency with which the series is recorded influences the choice of k , for example, with annual data it is necessary to choose $k = 1$.⁶ It is natural to

⁶A choice of $k = 1$ is necessary with annual data since a choice of $k > 1$ would result in there being very few turning points other than those associated with the great depression and the demobilization at the end of WWII

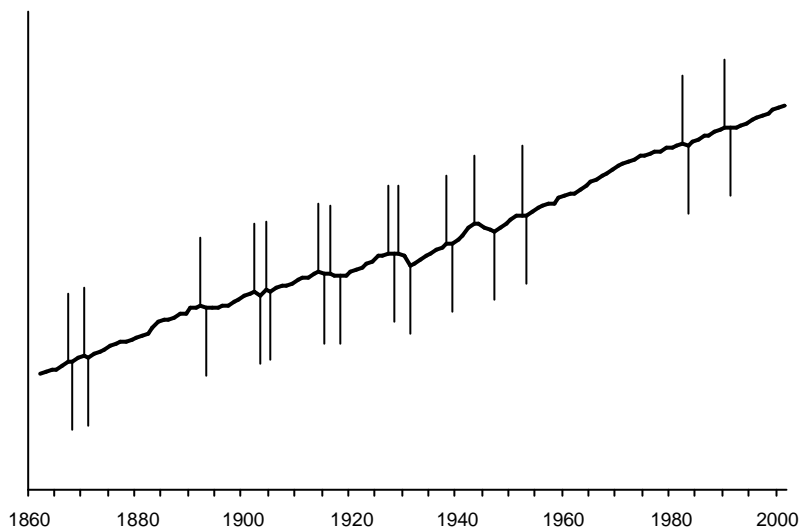
call this the *calculus rule* because it is a discrete version of the rule given above for locating turning points in differentiable functions.⁷

$$\text{Calculus rule: peak at } t \text{ if } \Delta y_t > 0 \text{ and } \Delta y_{t+1} \leq 0 \tag{1}$$

$$\text{Calculus rule: trough at } t \text{ if } \Delta y_{t+1} \leq 0 \text{ and } \Delta y_t > 0$$

Applying the calculus rule (1) to estimates of real Australian GDP yields the turning points identified in Figure 1.⁸ Here it is evident that in the period from 1861 through to federation major recessions were relatively rare in Australia. There was a long expansion lasting 21 years from the trough in 1870 through to the peak in 1891. The first half of the 20th century was a turbulent period for Australia with eight major recessions compared with only three major recessions in the second half of that century. I will return to detailed investigation of this data in section 3.

Figure 1: The Australian business cycle, annual real GDP, 1861-2000/01, dating via calculus rule.



Unlike Australia, statistical agencies in the United States generate a lot of very useful monthly data. Burns and Mitchell developed informal procedures that are suitable for locating turning points in such monthly data. These procedures were later formalized into a computer algorithm by Bry and Boschan

⁷This rule has been used by Estrella and Mishkin (1998) and Dow (1998).

⁸The estimates of real GDP for 1861 to 1938/39 are from Haig (2001). A different picture emerges if one uses Butlin's (1960) estimates.

(1971). In that algorithm peaks and troughs were defined as in the discussion above and k was set equal to 5 months. Most economic analysis is conducted with quarterly data and for this reason Harding and Pagan (2002b) take y_t to be a quarterly series and set $k = 2$ as an analogue and name the resulting rule as BBQ (Bry Boschan Quarterly). They define turning points, for quarterly data, in y_t in the following way.

$$\text{BBQ rule} \quad : \quad \textit{peak at } t = \{(y_{t-2}, y_{t-1}) < y_t > (y_{t+1}, y_{t+2})\} \quad (2)$$

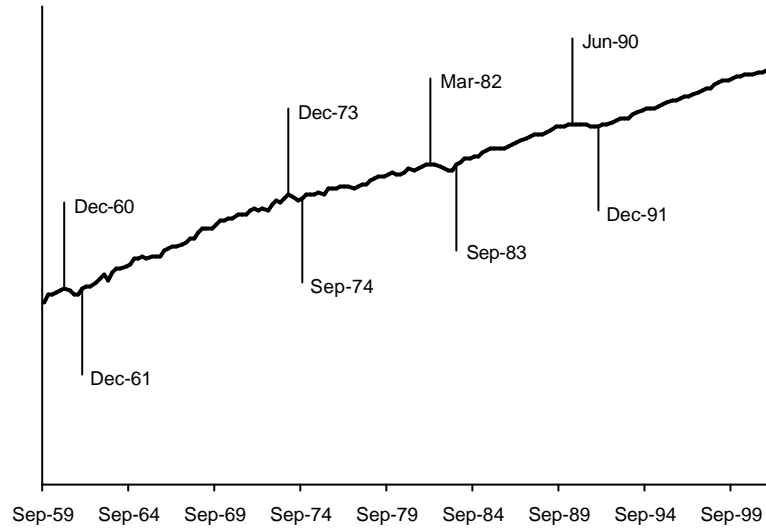
$$\text{BBQ rule} \quad : \quad \textit{trough at } t = \{(y_{t-2}, y_{t-1}) > y_t < (y_{t+1}, y_{t+2})\}.$$

In words, a recession occurs if the level of economic activity declines for two quarters and an expansion occurs if it increases for the same interval. In practice, the Bry and Boschan algorithm also applied some extra *censoring* procedures to the dates that emerged from applying the above rule. In particular the contraction and expansion phases must have a minimum duration of six months and a completed cycle must have a minimum duration of fifteen months. Harding and Pagan emulate this by imposing two quarter and five quarter minima to the phase lengths and complete cycle duration respectively. Further details on the algorithms that are used to find turning points in this manner can be found in Harding and Pagan (2002b) .

Applying the BBQ rule (2) to Australian quarterly GDP yields the turning points shown in Figure 2. It is evident that, as expected, the BBQ rule identifies more recessions than does the calculus rule applied to annual GDP. Indeed, BBQ identifies four recessions between 1959.3 and 2001.02 whereas only two recessions are located in annual data using the calculus rule for that period. The reason for this is that the calculus rule identifies recession events that are more extreme than are those identified via BBQ; Dow (1998) refers to them as major recessions.

Three points should be made here. First, where quarterly data is available that data provides a clearer picture of the business cycle than does annual data. Second, where quarterly data is unavailable annual data can provide some useful information about major recessions. Third, one should not confuse information obtained about the business cycle from annual data with that obtained using quarterly data as the two approaches relate to different concept of a recession. This last point is made more concrete by examining Table 1 which compares the features of the cycle located in annual GDP 1949/50 to 2000/01 via the calculus rule with the features of the cycle located in quarterly GDP 1959.3 to 2001.2 using the BBQ rule. Table 1 shows that, as would be expected, recessions located in annual GDP using the calculus rule are more severe economic events in the sense that they last longer and are less frequent than are recessions located in quarterly GDP via the BBQ rule. Looking at the average amplitude of contractions -1.17 per cent for annual data and -3.19 per cent for BBQ quarterly data one might question the statement that just made about the greater severity

Figure 2: Classical cycle turning points in quarterly Australian GDP, 1959.3 to 2001.4



of recessions located in annual data with the calculus rule but this result has a simple explanation. Take a simple case where the peak in quarterly GDP occurs at date t and the trough at date $t + 3$ and assume that the decline in GDP is sufficient to cause annual GDP to decline. Then letting y_t represent quarterly GDP the two amplitudes are calculated as

$$\text{Calculus amplitude (annual GDP)} = 100 * \left(\frac{y_{t+1} + y_{t+2} + y_{t+3} + y_{t+4}}{y_{t-3} + y_{t-2} + y_{t-1} + y_t} - 1 \right)$$

$$\text{BBQ amplitude (quarterly GDP)} = 100 * \left(\frac{y_{t+3}}{y_t} - 1 \right)$$

It is evident that the two amplitudes measure different things and cannot (should not) be compared.

2.2 Aggregating turning points to obtain a reference cycle

Burns and Mitchell developed a methodology for studying the business cycle that can be applied when there exists no reliable single series such as GDP to measure economic activity. This method continues to be used in the United States by the the National Bureau of Economic Research (NBER) business cycle dating committee which maintains a semi-official list of dates of peaks and

Table 1: Comparison of the business cycles located with the calculus and BBQ rules 1959/60-2000/01

Rule	Annual GDP	Quarterly GDP
	1949/50 to 2000/01	1959.3 to 2001.4
	Calculus	BBQ
#peaks	3	4
#troughs	3	4
PT (Contraction)		
Duration (quarters)	4	3.75
Amplitude (percent)	-1.17	-3.19
TP (Expansion)		
Duration (quarters)	72	36.0
Amplitude (percent)	75.37	40.84

troughs in US economic activity that is referred to as the NBER business cycle chronology. Ernst Boehm, working at the Melbourne Institute, in conjunction with Geoffrey Moore⁹ constructed and maintained a similar chronology for Australia.¹⁰

A key issue in extracting cycle information from several series relates to how one combines that data to arrive at a single measure of the business cycle. In the approach discussed in the preceding section the series y_{jt} are aggregated to produce a y_t^a (ie GDP) and which is then segmented via the rules discussed above to produce turning points; Harding and Pagan (2001a) refer to this as locating *turning points in an aggregate*.

In the NBER strategy a number of series y_{jt} are selected and the methods described previously are used to find the turning points in each of these, leading to binary variables S_{jt} that take the value 1 if the j^{th} variable is in expansion and zero otherwise. Subsequently, the S_{jt} are combined to produce a series that represents the phase states S_t^a in the aggregate level of economic activity y_t^a . Harding and Pagan (2001a) refer to this procedure as the *aggregation of turning points*. It leads to the NBER's *reference cycle*. An algorithm to replicate the NBER's procedures for aggregating turning points is described in Harding and Pagan (2002b) which also documents the capacity of that algorithm to replicate the reference cycle. This algorithm is based on the NBER procedures as documented by the late Geoffrey Moore; the clearest description of those procedures are in Boehm and Moore (1984).¹¹

Harding and Pagan (2001a) suggest that one should think about this algorithm for aggregating turning points and the rules for locating turning points in

⁹The late Geoffrey Moore was a long-time member of the NBER business cycle dating committee.

¹⁰It is available from the Melbourne Institute web page at <http://www.ecom.unimelb.edu.au/iaesrwww/bcf/bdates5197.html>.

¹¹See also the description of the procedure in Moore and Zarnovitz (1986 p772). The latter relates to the determination of a reference growth cycle but can be easily amended to construct a classical reference cycle via the aggregation of turning points.

Table 2: Comparison of Boehm-Moore reference cycle dates for Australia and chronology obtained from applying BBQ to chain weighted real GDP

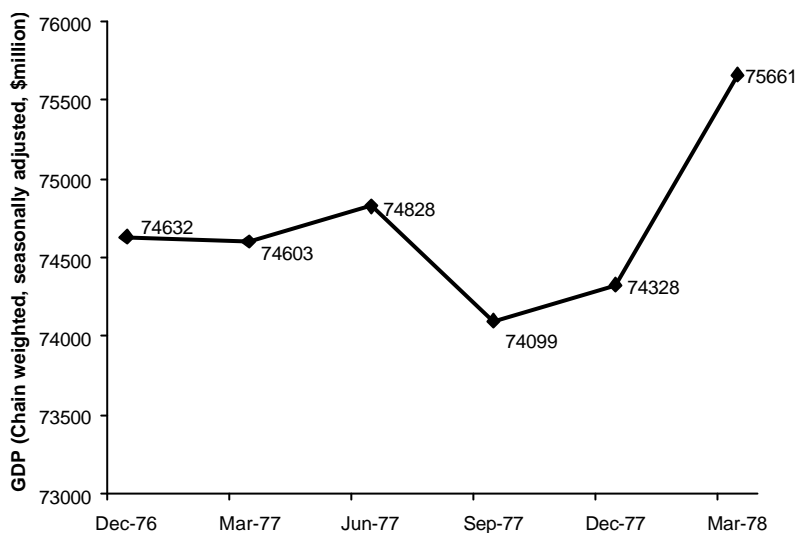
Boehm		BBQ (Chain volume GDP)	
Peak	Trough	Peak	Trough
60.3		60.4	
	61.3		61.4
74.3 (74.1)		73.4	
	75.4 (75.1)		74.3
76.3			
	77.4		
81.3 (82.2)		82.3	
	83.2		83.3
89.4 (90.1)		90.2	
	92.4 (91.3)		91.4

GDP in the same way that we think about Taylor rules. It is not that a Taylor rule re-produces the actual decisions made by the US Federal Reserve Bank about the Federal Funds rate but that it is a good enough approximation to be a useful tool for summarizing their decisions. Thus the algorithms mentioned above provide useful tools for investigating the procures of the NBER business cycle dating committee and the procedures used by Boehm and Moore (1984) for Australia.

A starting point in such an investigation would involve comparing the business cycle turning points established by applying BBQ to quarterly GDP with decisions actually made about the location of turning points. Harding and Pagan (2001,2002) make that comparison for US GDP and find that the fit is very good with the post WWII NBER reference cycle. A similar comparison is reported Australia in Table 2. Here the reference cycle is the one developed at the Melbourne Institute by Boehm and Moore (1984) and updated by Boehm(1994,1998). The alternative chronology is obtained applying BBQ to quarterly chain volume Australian GDP.

Evidently, the fit between the BBQ(GDP) chronology and the Boehm-Moore reference cycle is not as good as for United States. BBQ does not identify the Boehm-Moore cycle that starts with the trough in 1976.3 and ends with the peak 1977.4. As is shown in Figure 3 the reason for this is that the fall in GDP in September quarter 1977 is mild (0.4 per cent) and short lived as GDP rises in December 1977. This period is of particular interest as it provides a good example of the censoring rules that form part of the BBQ dating procedure. The peak would be placed in June 1977 and the trough in September 1977, but since this leads to a contraction phase of duration one quarter this cycle is eliminated by the censoring rule that requires phases to have a minimum duration of two quarters. In short, this cycle is eliminated because it is not considered to be a sufficiently prolonged or deep contraction in GDP as to warrant the label recession.

Figure 3: GDP (Chain weighted and seasonally adjusted) 1976.4 to 1978.1



Some of the other differences between the two chronologies are easily explained. Boehm puts a peak at 74.3 but inspection of the six components of the coincident index shows that five of those components reached a peak in February 1974 and one (real household income) reaches a peak in May 1974.¹² Thus the peak of the reference cycle should be at 74.1. Similarly, Boehm put a reference cycle trough at 75.4 whereas inspection of the components of the coincident index suggests that the trough is more appropriately placed at 1975.1. These differences are most likely attributable to revisions to the data made by the ABS since Boehm last updated the chronology. In Table 2 revised dates of the reference cycle based on the latest data are placed in parentheses. Inspection of Table 2 shows that once these revisions are taken into account the match between the chronology obtained via *turning points in the aggregate* and the chronology obtained via the *aggregation of turning points* is much closer than first seemed to be the case.

Two points flow from the discussion above. First, it is necessary to update the business cycle chronologies when the data is revised. This is a practice that has been eschewed by those following the NBER methodology but this latter approach results in anachronisms as shown above. This point is particularly important in circumstances where statistical agencies are frequently revising their estimates. Second, the use of algorithms to produce such chronologies makes

¹²The six components of the Westpac-Melbourne Institute coincident index are real household income, real non farm product, industrial production, real retail sales, total civilian employment and the unemployment rate inverted.

those chronologies replicable something that is not the case with chronologies that result from the exercise of judgement.

2.3 The Growth Cycle and the output gap

The growth cycle refers to the recurrent pattern of peaks and troughs in a series z_t from which a deterministic trend has been removed. To make this precise let T_t be a deterministic trend in y_t and z_t be the deviation from that trend viz

$$z_t = y_t - T_t$$

Then, the growth cycle is the pattern of peaks and troughs in z_t . Growth cycle peaks (troughs) identify dates at which the economy moves from a sustained period of growth above the trend rate to a sustained period of growth at below the trend rate.

Harding and Pagan (2001a) observe that one reason for investigating cycles in z_t is that these quantities often appear in applied macro-economic models as “output gaps” or measures of “disequilibrium” and so may be important in connecting the nominal and real sides of the economy. In these cases T_t may not be a deterministic trend rather it might be a measure of potential output such as that constructed for the US by the Congressional Budget Office.

See Harding and Pagan (2001) for an example of how studying the cyclical behaviour Euro area output gaps can provide information on the difficulties that may be encountered by the European Central Bank when seeking engage in a common monetary policy.

2.4 The location of turning points via regime switching models

The approach outlined in the preceding section proceeds by locating turning points in y_t or (z_t for growth cycles) and these turning points are then used to segment the sample into periods of business cycle (growth cycle) expansions and contractions. A binary random variable S_t that takes the value unity in expansions and zero in contractions is employed to represent the cycle. The method just described for producing realizations of the random variable S_t from y_t is essentially non-parametric in nature. Other methods have been suggested to construct analogues of the S_t that are based on parametric statistical models. A popular class of methods is associated with Markov Switching (MS) models introduced by Hamilton (1989). In this approach a series such as GDP is modelled as

$$\Delta y_t = \mu_j \zeta_t + \sigma_j \zeta_t e_t \quad , j = 0, 1 \quad (3)$$

where $e_t \sim n.i.d.(0, 1)$. The random variable ζ_t can take on the values zero or one only and evolves as a Markov Chain with transition probabilities $P(\zeta_t = j | \zeta_{t-1} = k) = p_{kj}$. The sample is segmented into expansions and contractions using the criterion

$$\begin{aligned}\xi_t &= 1 \quad \text{if } (\Pr(\zeta_t = 1 | \mathfrak{S}_t) > .5) \\ &= 0 \quad \text{otherwise}\end{aligned}$$

where \mathfrak{S}_t is composed of either $\{\Delta y_{t+s}\}_{s=-\infty}^0$ or $\{\Delta y_{t+s}\}_{s=-\infty}^{\infty}$ depending on whether one wants filtered or smoothed estimates of the probability. Thus the binary random variable is then said to be in a recession state when ξ_t takes the value zero and in expansion when it takes the value unity.

One might ask how the regime switching approach compares with the peak and trough dating method outlined earlier. Diebold and Rudebusch (2001, p6) suggest that the answer is that

“..it is only within a regime switching framework that the concept of a turning point has intrinsic meaning...One can of course define turning points in terms of features of sample paths, but such definitions are fundamentally as hoc”,

However, as Harding and Pagan (2002a) observe the regime switching approach is simply another method of segmenting a sample into expansion and contraction states and thus Diebold and Rudebusch’s answer seems rather misleading.

An answer to the question about the relative merits of the two approaches has three parts. First, for policy work and public discussion it is essential to have a method of segmenting y_t in expansions and contractions that is consistent with a widely accepted definition of what constitutes a recession. Harding and Pagan (2002a) argue that doing the segmentation with (2) to produce S_t makes sense because it uses a widely accepted definition of what constitutes a recession. Moreover, they looked at a simple example in the US context to argue that the MS dating rules that produce ξ_t effectively involve a combination of past and future values of Δy_t but there was no connection between these rules and any popular idea of what constitutes a recession. One can find situations where ξ_t and S_t are highly correlated, as in Hamilton (1989), but the failure of the Hamilton rule to identify the US recession of the 1990’s shows that such correlation is not guaranteed.

Second, Harding and Pagan (2002a) observe the segmentation of series via the location of turning points in the sample path provides a robust non-parametric data summary of the business cycle features much as the autocorrelation function summarises serial dependence. It is wise to proceed by checking whether parametric models can match the features of the data that are of interest. Thus, just as the autocorrelation function is used for this purpose the segmentation performed with (2) to produce S_t should be used to check whether regime switching models such as the markov switching one above can match the business cycle features of the data. Harding and Pagan (2002a) show that when such a comparison is made the regime switching models are found not to match the facts found via non-parametric methods.

Third, a number of problems are encountered in the estimation of regime switching models. One problem identified by Goodwin (1993) is that the likelihood function is typically badly behaved for certain markov switching models

often exhibiting numerous local optima, thus the starting values chosen by the researcher to initiate the maximum likelihood estimation algorithm can influence what is found. In short the algorithm may not converge to a global optimum. Breunig and Pagan (2001) discuss some tests that can identify when such non-convergence is a problem. These tests ask whether markov switching models can replicate the first few moments of the data ie mean, variance, autocovariances. They find that several papers in the literature report results from MS models where the parameters are not at a global maximum of the likelihood function. Breunig and Pagan also show how one can explore the important question of whether the non linearity introduced via the markov switching model is relevant to the business cycle.

2.5 The unseen cycle

A useful distinction is made between what is called the “seen” the “unseen” cycles. The former is the familiar recurrent pattern of peaks and troughs in the level of a time series such as GDP that has been the focus of discussion in the preceding sections while the latter can be defined in two closely related ways. The first of these is via the pattern of local peaks and troughs in the covariance between the current value of a time series and its lagged values. That is, with the unseen cycle $\gamma_k = cov(y_t, y_{t-k})$ is examined to see if it has local peaks and troughs and if such can be found the series is asid to be cyclical. The second approach examines the spectrum to see if it contains turning points. Peaks in the spectrum represent frequencies that account for particularly proportion of the variation in y_t .

The spectrum is defined as

$$s(\omega) = \frac{\gamma_0}{2\pi} + \frac{1}{\pi} \sum_{\tau=1}^{\infty} \gamma_{\tau} \cos(\tau\omega) \quad 0 \leq \omega \leq \pi \quad (4)$$

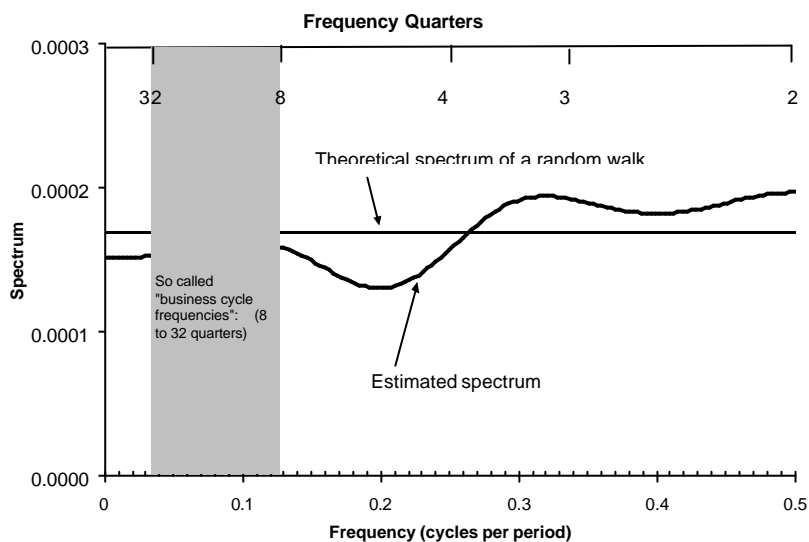
where ω is the frequency and γ_{τ} is the covariance between y_t and y_{t-k} . As discussed in Harding and Pagan (2001a) there is no relationship between the cycle defined via turning points in the level of a series and the cycle defined via the spectrum. Despite this one often hears the expression fluctuations at the cyclical frequencies. The later referring to fluctuations with period between 8 and 32 quarters.

Although frequently used the unseen cycle approach suffers from three problems. First, in order to apply these techniques one must render y_t stationary this is typically done by applying a filter to y_t . Filtering can be something as simple as taking the first difference of the log of the series (ie. $\Delta y_t = y_t - y_{t-1}$), applying a 13 term Henderson filter to obtain as is done at the ABS to obtain their measure of “trend”, or it can be more complicated as is the case with the Hodrick Prescott filter and band-pass filters. One cannot reasonably take a position for or against filtering it all depends on the use to which the filtered data is to be put and on whether the filter is known to introduce distortions. Where the filtered data is to be used in policy making a central requirement is

that it speak about things that are experienced by real people and this argues for doing no more than taking differences. It has been established that the Hodrick Prescott filter will induce an unseen cycle in the filtered series even if the original series has been constructed so that it contains no unseen cycle.¹³ This later property is a very good reason to avoid the use of such filters.

A second problem is that the unseen cycle only relates to second moments (covariances) whereas interest centres on the first moment (trend growth rate) and on the higher moments such as the third and fourth moments that provide information on the fatness of the tails of the distribution of Δy_t and the skewness of that distribution. These features of the distribution influence the relative frequency of large shocks and the relative frequency of negative and positive shocks respectively.

Figure 4: Spectrum of first difference of logarithm of real Australian GDP, 1959.3 to 1998.1



A third problem with use of the spectrum to study business cycles arises because the notion that economic aggregates such as economic activity exhibit peaks in their spectrum of Δy_t is contradicted by some basic economic reasoning that was clearly stated by Irving Fisher (1925). He observed that with the unseen cycle there is a particular periodicity to fluctuations. In short, if there were pronounced peaks in the spectrum at business cycle frequencies then busi-

¹³Cogley and Nason (1991) and Soderlind (1994) point out that if y_t is generated as $y_t = 0.95y_{t-1} + e_t$, where e_t is distributed iid normal with mean 0 and variance σ^2 . Then the Hodrick-Prescott filtered y_t has a peak in its spectral density at business cycle frequencies even though no such peak exists in the spectrum of the original series y_t .

ness people and policy makers could plan sometime in advance on when they were going to experience booms and busts. Put in this way it clear why the unseen cycle has little relevance to economics — consumers and business people and policy makers would adjust their plans in response to such periodicity. The upshot is that economic system produces data that exhibits little evidence of periodicity. For example, Figure 4 shows the spectrum of Δy_t for the period 1959.3 to 1998.1 where y_t is the logarithm of GDP. The particular vintage of GDP chosen is the last before the introduction by the ABS of the chain volume measure of GDP. I have chosen this vintage so that I can discuss, later in the paper, the measurement error associated with the chain volume measure. Turning to Figure 4 two points are evident. First, there is little evidence of a peak in GDP at the business cycle frequencies — the spectrum is almost flat over this range. However, there is a trough in the spectrum at about 5 to 6 quarters and there a significant proportion of the variance explained by fluctuations at frequency below 4 quarters. The later can be interpreted as a sign of measurement error. Specifically, the ABS may have some difficulty in locating the exact quarter in which production occurs. In subsequent sections taking such measurement error into account will be an important part of my explanation of aparent changes in the business cycle.

An ARMA(p,q) model was estimated for Δy_t using the March quarter 1998 vintage of data. I searched over all lag structures with $p \leq 4$ and $q \leq 4$ using Schwartz’s (1978) Bayesian information criteria. The model selected was a random walk ie ARMA(0,0) which has a horizontal line as its theoretical spectrum. The later is plotted on Figure 4. It is clear from figure 4 that the estimated spectrum is close to that of a random walk.

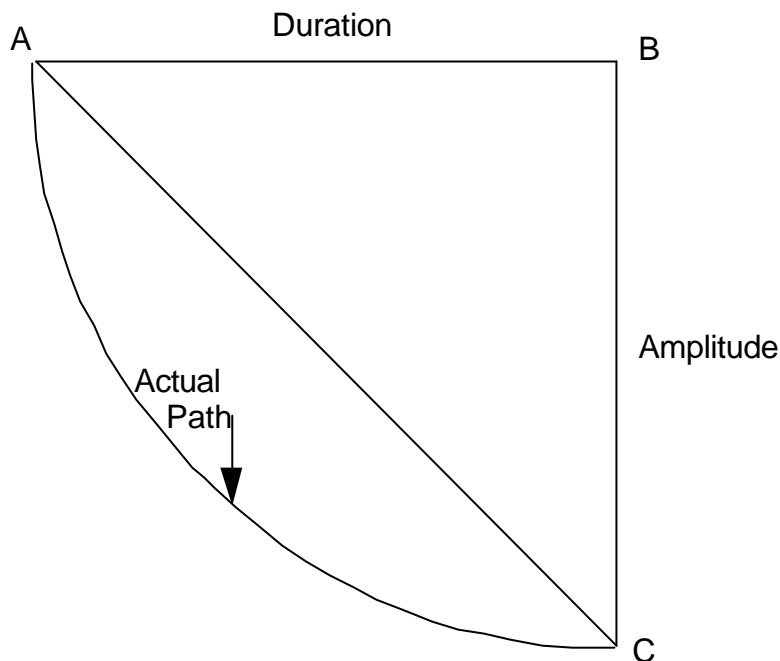
3 Changing features of the Australian business cycle

This section explores major expansions and contractions in the Australian business cycle using the calculus rule (1) to locate turning points in annual GDP from 1861 to 2000/01. These turning points are shown in Figure 1.

When describing business cycles it is useful to consider a stylized representation of business cycle phases such as is done in Figure 5 which shows a stylized recession. The height of the triangle is the amplitude A of the phase and the base is its duration D . From these two quantities one can calculate the area of the triangle which approximates the cumulated losses in output from peak to trough. Using the subscripts to denote the i^{th} phase, the product $C_{T_i} = .5(D_i * A_i)$ represents the "triangle approximation" to the cumulative movements in output over the phase. Of course, the observed cumulative movements (C_i) may differ from C_{T_i} since the actual path through the phase will deviate from the triangle approximation. The extent of the deviation is measured by the average excess cumulated movements defined as, $E_i = (C_{T_i} - C_i + 0.5 * A_i) / D_i$. In this formula D_i is the duration of the phase and the term $0.5 * A_i$ removes the bias that arises

in using a sum of rectangles (C_i) to approximate a triangle. The importance of E_i is that it measures the extent to which the actual path between successive turning points departs from a linear one.

Figure 5: Stylized representation of a recession phase as a triangle



3.1 Have major expansions become longer and contractions shorter and shallower?

The question asked in the title of this section can be answered by comparing average phase durations and amplitudes across sub periods of time. Table 3 provides the information for such a comparison. Comparing column 5 which relates to the period 1950/51 -2000/01 with column 2 which relates to the full sample (1861-2000/01) it is evident that in the second half of the 20th century major contraction phases are somewhat shorter (1 year versus 1.36 years) and considerably shallower (1.17 versus 4.46 per cent from peak to trough). Major expansion phases are considerably longer 18 compared to 8.15 and exhibit a much greater amplitude 75.37 per cent versus 35.14 per cent.

A surprising feature of Table 3 is that the business cycle in the second half of the 19th century looks remarkably similar to the business cycle in the second half of the 20th century and it is the first half of the 20th century that appears

Table 3: Average features of major Australian expansions and contractions 1861-2000/01

	Full sample	1861-1900	1900/01-1949/50	1950/51-2000/01
Number of peaks	14	3	8	3
Duration (years)				
Contractions	1.36	1.00	1.63	1.00
Expansions	8.15	11.50	4.57	18.00
Amplitude (per cent)				
Contractions	-4.46	-1.88	-6.67	-1.17
Expansions	35.14	47.87	22.15	75.37
Cumulative (per cent)				
Contractions	-4.21	-0.94	-6.80	-0.59
Expansions	283.01	471.17	74.10	1011.23
Excess (per cent)				
Contractions	0.18	0.00	0.32	0.00
Expansions	0.48	1.28	-0.35	3.09

to be the outlier. For example, the durations of contractions were identical at 1 year in both periods. Contractions were a little shallower in the second half of the 20th century -1.17 per cent compared with -1.88 per cent in the 19th century. Major expansions were about 6.5 years longer in the late 20th century than in the 19th and the amplitude of expansions was much greater (75.37 per cent) versus (47.87 per cent).

In the first half of the 20th century contractions were much longer (1.63 years) and expansions were much shorter (4.57 years) than in the late 19th or late 20th century. Contractions in the first half of the 20th century were much deeper (amplitude -6.67 per cent) and expansions much shallower (22.15 per cent) than in either of the two other half centuries. This should serve to make the point that improvements in the business cycle are not guaranteed or automatic. A point that is reinforced by considering the difficulties that Japan has faced for more than a decade.

3.2 Has the business cycle changed over the past forty years?

The preceding sections have dealt with major expansions and contractions as identified in Annual GDP via the calculus rule (1). In this section I discuss the business cycle as located in quarterly data via the BBQ rule (2). The turning points identified with BBQ in chain volume GDP 1959.3 to 2001.4 were shown in Figure 2 earlier. Table 4 shows the duration and amplitude of each of the four contractions. It is immediately obvious that the durations of the last two contractions (5 quarters each) is considerably greater than the duration of the earlier contractions (3 and 2 quarters) respectively. Thus there is no evidence that contractions are getting shorter. Things are less clear in regard

amplitude. The most recent contraction was very shallow (Amplitude -1.16 per cent) but the 1982/83 contraction was the deepest observed (Amplitude -4.01 per cent). Nonetheless, the average of these last two contractions (-2.58 per cent) is somewhat smaller than the average of the earlier two contractions (-3.51 per cent) suggesting that there has been some moderation in amplitude in recent times. Although it does not seem to be as marked as would be suggested by popular discussion.

Table 4: Amplitude and Duration of four contractions in Australian quarterly GDP 1959.3 to 2001.4

Peak	Trough	Duration (quarters)	Amplitude (per cent)
1960.4	1961.4	3	-3.89
1973.4	1974.3	2	-3.69
1982.1	1983.3	5	-4.01
1990.2	1991.4	5	-1.16

Table 5 reports the duration and amplitude of the three completed expansions together with the current duration and amplitude of the yet to be completed expansion. While the current expansion is longer than either of the previous two expansions it still has some way to go before reaching the 49 quarters of the long expansion from 1961.4 to 1973.4. Similarly, while the amplitude of the current expansion is greater than the previous two it still has some way to go before matching the long expansion that ended in 1973.

Table 5: Amplitude and duration of three completed and one uncompleted expansion in quarterly GDP, 1959.3 to 2001.4

Trough	Peak	Duration (quarters)	Amplitude (per cent)
1961.4	1973.4	49	67.75
1974.3	1982.1	31	23.62
1983.3	1990.2	28	31.15
1991.4	?	>40	>38.67

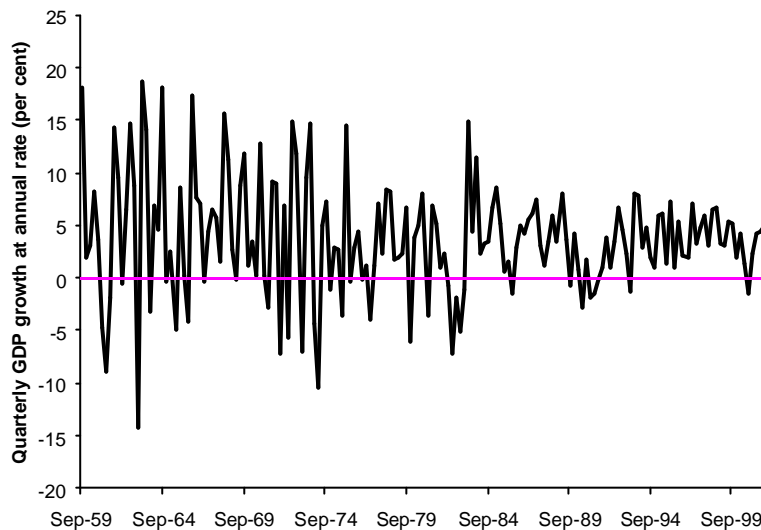
In short, there is relatively little evidence from business cycle statistics to suggest that the Australian contractions have become shorter and expansions longer. However, there is some weak evidence to suggest that contractions are a little shallower now than in the past.

4 Has there been a decline in volatility of quarterly Australian GDP?

The conclusion just reached in the preceeding section will no doubt be surprising and controversial. To understand why this is so one need only look at Figure 6 which shows the quarterly percentage change in chain volume GDP at annual

rate (ie. $400*\Delta y_t$). The Figure suggests that there has been a big reduction in the volatility of GDP. Given that the probability of a recession is an decreasing function of the ratio of average GDP growth to its standard deviation one might think that Figure 6 furnishes convincing evidence that the Australian business cycle has moderated. But this is not the case let me explain why.

Figure 6: Annualized first difference of logarithm of quarterly chain volume Australian GDP, seasonally adjusted, 1959.3 to 2001.4

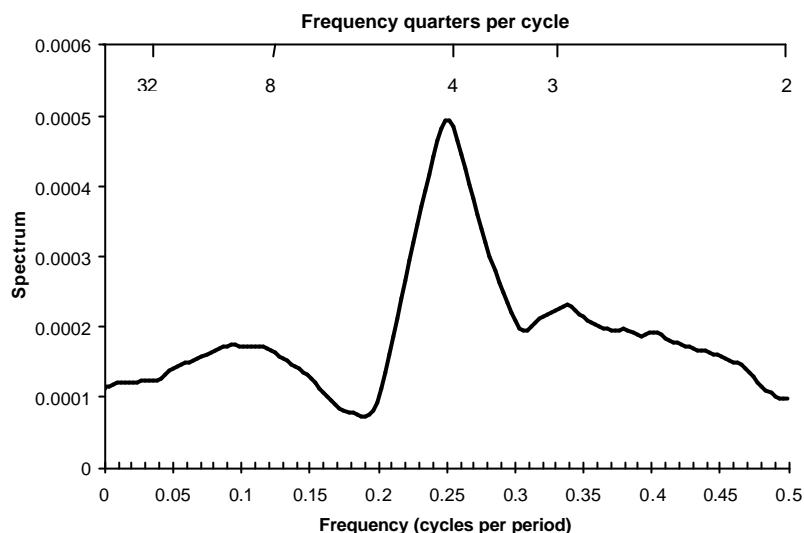


The conflict between the story about the business cycle implicit in Figure 6 and that told in the preceding section suggests that one need to investigate the properties of the data further. A useful starting point for such an investigation is the spectrum. This is shown in Figure 7. Comparison of Figures 7 and 4 indicate that the December 2001 vintage of “seasonally adjusted” GDP has a more pronounced peak at at the annual frequency (4 quarters per year) and a trough at frequency 5 quarters than the March 1998 vintage of GDP data.¹⁴ This suggests that the ABS seasonal adjustment procedures have not adequately removed seasonality from the chain volume GDP data.

To investigate the proposition that the ABS has not removed all of the seasonality from chain volume GDP I examine the periodogram of the December quarter 2001 vintage of GDP — The spectrum is a smoothed version of the periodogram. The periodogram is shown in Figure 8 and shows a mark peak at the annual frequency suggesting that the ABS have not fully removed seasonal effects.

¹⁴The data on chain volume GDP is taken from PC AUSSTATS table 5206.05 row 55 “Gross Domestic Product”

Figure 7: Spectrum of seasonally adjusted chain volume Australian GDP, 1959.3 to 2001.4

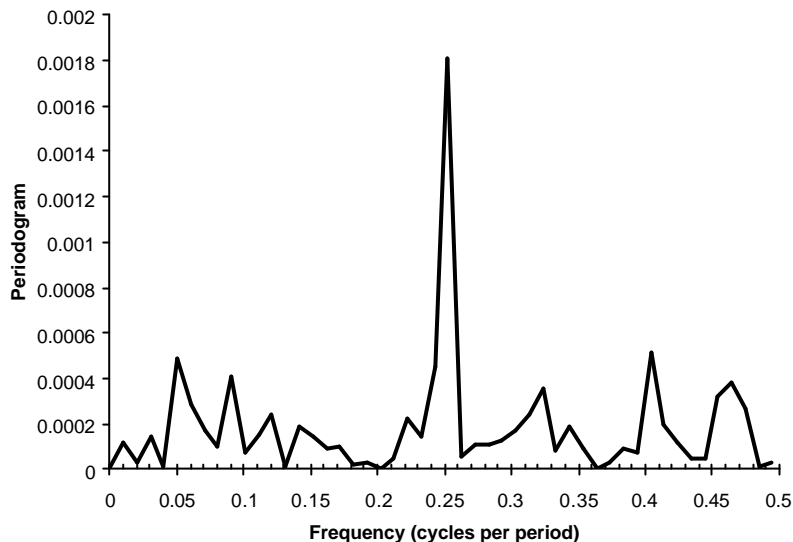


Thus the evidence suggests that the ABS has not completely removed the seasonal component from GDP. If the ABS seasonal adjustment procedures do not remove all of the seasonality from GDP in the earlier part of the period but remove more of the seasonality from the latter period then this would account for the reduction in volatility seen in 6. A simple test of this hypothesis involves examining the four quarter change in GDP (ie $100 * (y_t - y_{t-4})$) if there is a problem with inconsistent application of seasonal adjustment procedures then that will be demonstrated by this device. It is evident from Figure 9 which shows the 4 quarter change in quarterly GDP that there is a problem with the consistency with which the ABS seasonal adjustment procedures have been applied. This latter feature of the data accounts for much of the reduction in volatility that is apparent in Figure 6. In short, the bulk of the volatility seen in Figure 6 prior to the mid 1980s was attributable to measurement error by the ABS.

4.1 Evaluating the change in volatility of Australian GDP

Simon (2001) in a recent RBA paper reports 5 year moving averages of the standard deviations of the quarterly change in Australian GDP and from that concluded that there had been a significant reduction in volatility. However, the discussion above suggests that the apparent reduction in volatility largely reflects reduction in the residual seasonality in GDP rather than a reduction in

Figure 8: Periodogram of chain volume GDP, 1959.3 to 2001.4



the underlying volatility of GDP. To make this argument more precise Figure 10 compares the 21 quarter centered moving averages of $0.25 * (400 * \Delta y_t - \mu)^2$ with $(100 * (y_t - y_{t-4}) - \mu)^2$. The former approximates Simon's measure and the latter is the alternative quantity involving the fourth difference of GDP.¹⁵ Clearly, once ABS's problem with seasonal adjustment is taken into account there is far less evidence for the calimed reduction in the volatility of GDP.

One complaint that might be lodged about the analysis above is that 21 quarters is rather short for the estimate of a the standard deviation. Figure 11 reports the estimates redone with 41 quarter centered moving averages. As can be seen from Figure 11 the longer period over in the moving average makes it clear that the neglected seasonality in GDP leads one to overemphasise the extent of any decline in the volatility of GDP. Notice that once the residual seasonal effect is removed from GDP it is evident that the volatility of output rose in the mid to late 1970s. This was a period of large aggregate supply shocks and in which monetary policy was set by a cabinet dominated by farmers and miners. Thus the increased volatility of GDP is exactly what one might expect.

The effect on the apparent volatility of GDP of neglected seasonality discussed above raises the issue of how other forms of measurement error might impact on the volatility of GDP. The National Accountant compiles an ex-

¹⁵The main difference between what is done here and in Simon's RDP is that I have chosen to centre the moving average so that it furnishes an undistorted picture of the timing of changes in volatility. I have also divided Simon's measure by 4 so that the two variances are in the same units.

Figure 9: Change in chain volume Australian GDP over the same quarter of the previous year, 1959.4 to 2001.4 (per cent)

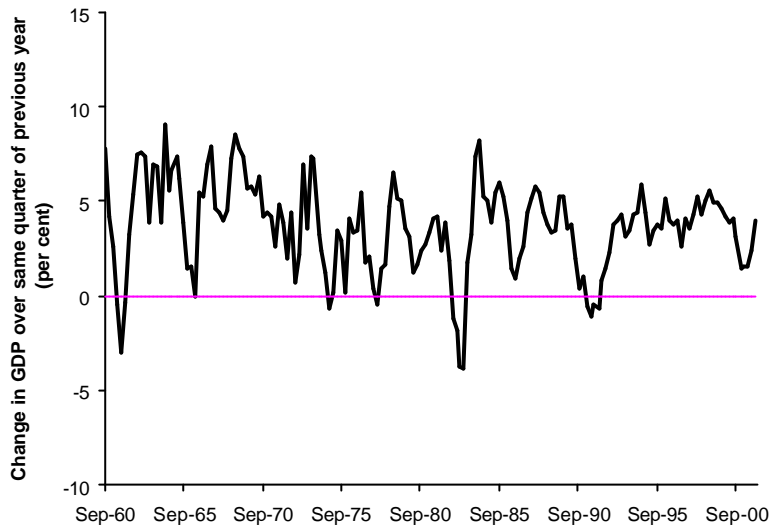


Figure 10: Twenty-one-quarter centered standard deviations of the change in GDP, 1959.3 to 2001.4

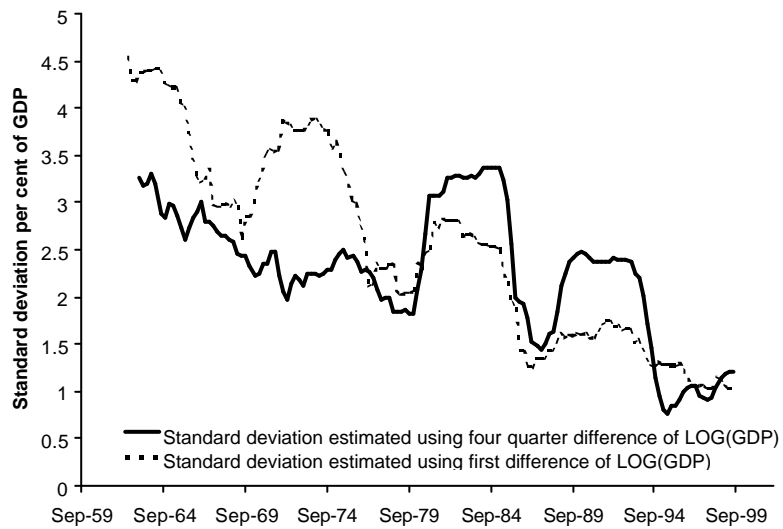
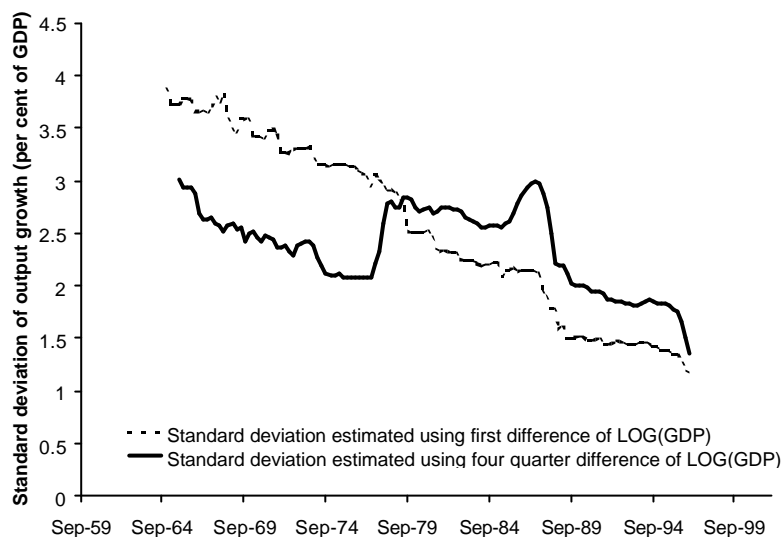


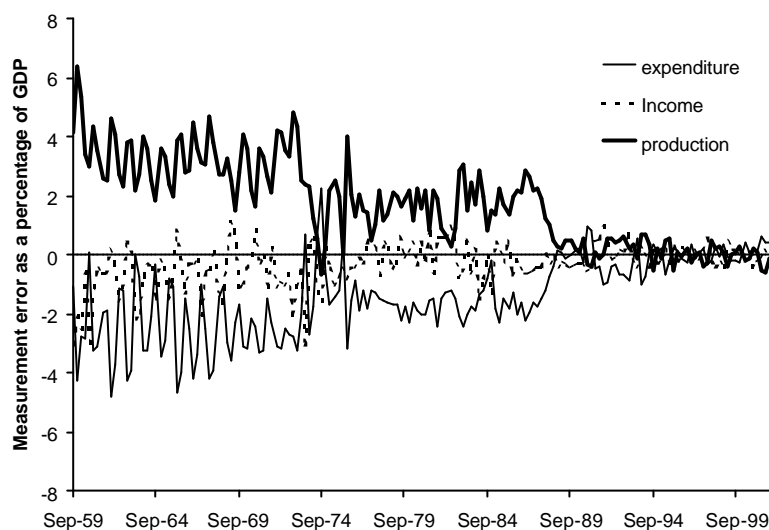
Figure 11: 41 quarter moving standard deviation of GDP growth, 1959.3 to 2001.4



penditure account, an income account and a production account. In principle consumption plus investment plus government expenditure plus exports minus import should add to an expenditure measure of GDP (GDPE). Similarly factor incomes should add to an income measure of GDP (GDPI). And the value added of industries should add to a measure of GDP (GDPI). In principle these three measures of GDP are identically equal. Of course, in practice measurement error means that they differ — the income and expenditure statistical discrepancies provide a measure of the size of the errors on the income and expenditure accounts. The National Accountant does not publish a measure of the production statistical discrepancy but one can be estimated by assuming that the income, expenditure and production statistical discrepancies add to zero. Figure 12 shows my estimates of the magnitudes of this type of measurement error expressed as a percentage of GDP in the same quarter. As can be seen from Figure 12 the ABS has reduced expenditure and production measurement error from an average of 3 per cent of GDP in the 1960s to being almost negligible in the 1990s. Some account must be made for this feature when assessing the changes in the volatility of GDP so that one can ascertain how much of any change in volatility is attributable to changes in measurement practices and how much is attributable to improved macroeconomic management.

A very rough separation of the volatility of GDP into these two components can be obtained by the following calculation. First, assume that the unobservable expenditure, income and production measurement errors are independent

Figure 12: Income, Production and Expenditure measurement error in chain volume national accounts

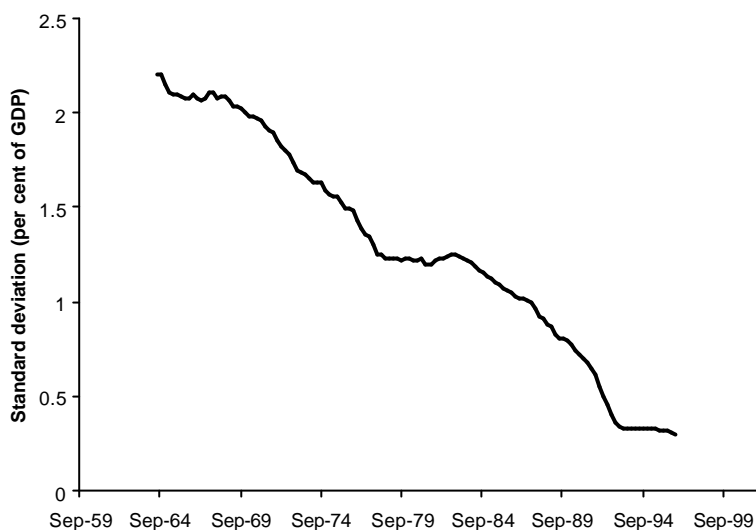


(the observable expenditure, income and measurement errors cannot be independent since they are constructed to sum to zero) then approximate the variance of the measurement error in GDP by one ninth of the sum of the squares of the three observable measurement errors.¹⁶ Now assuming that the measurement errors are not serially correlated the variance of the measurement error in first difference of GDP is approximately twice the variance of the measurement error in the level of GDP. The square root of this quantity is then a rough (biased) estimate of that part of the standard deviation in the change in GDP that is attributable to measurement error via the statistical discrepancies. A 41 quarter moving standard deviation of the measurement error in the quarterly change in GDP is shown in Figure 13. It is evident that much of the apparent reduction in the volatility is attributable to changes in measurement practices at the ABS rather than to improvements in macroeconomic policy making.

To provide a very rough idea of how much this matters I have subtracted the estimated standard deviation of the change in GDP attributable to measurement error from the estimate of the volatility of GDP in Figure 11 to obtain Figure 14. This figure suggests that viewed over 40 years there has not been a reduction in the volatility of GDP growth rather there has been a change in how the ABS

¹⁶To the purist who will be, appropriately, horrified by the approximations made here I offer the observation that inspection of the Figure suggests that the bulk of the “measurement error” is not true mean zero measurement error but rather a deterministic bias in the National Accountant’s procedures which has been removed over time. The approximations made here are then quite reasonable in this circumstance.

Figure 13: Rough estimate of the standard deviation of the change in GDP that is attributable to measurement error



accounts for seasonality and a reduction in measurement error by the ABS.

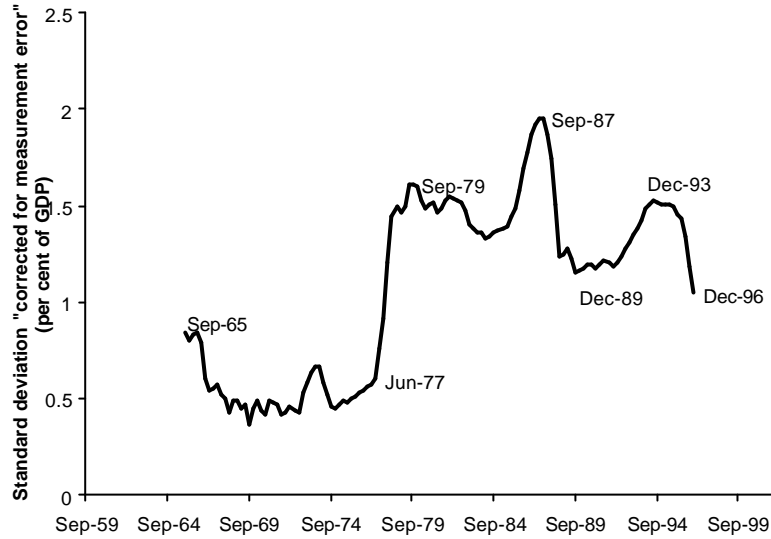
As can be seen from Figure 14 the late 1970s showed a sharp worsening in GDP volatility for the reasons alluded to earlier. As monetary policy came under the control of an independent central bank we saw a marked reduction in volatility of GDP during the 1990s. However, Figure 14 suggests that once neglected seasonality and changes in the ABS's measurement practices are taken into account there is little evidence of a trend decline in the volatility of GDP.

5 The (un)predictability of major turning points

Irving Fisher's observation that the workings of the market place will operate to make it difficult to predict macroeconomic aggregates can also be applied here where it manifests itself as the hypothesis that turning points should be hard to predict on the basis of information about the duration of phases alone.¹⁷ If this were not the case then business people and consumers would be able to profit by rearranging the timing of their actions. This hypothesis implies that

¹⁷This does not mean that turning points cannot be predicted nor does it necessarily mean that GDP is unpredictable at higher frequencies ie (quarterly). What the hypothesis does say is that turning points should not be too easily predictable since if they were people and policy makers would be able to profit by changing their plans.

Figure 14: 41 quarter moving standard deviation of the volatility of GDP after correcting for neglected seasonality and measurement error



the durations of expansions and contractions are governed by distributions that are well approximated by the geometric distribution. Specifically, let d denote duration and p represent the probability that the current phase will continue then, $f(d)$ the geometric distribution $f(d)$ is defined as

$$f(d) = p^{d-1} (1 - p) \quad d = 1, 2, \dots \quad (5)$$

It has a cumulative density function

$$\begin{aligned} Pr(D \leq d) &\equiv F(d) \\ &= \sum_{j=1}^d p^{j-1} (1 - p) \\ &= (1 - p^d) \end{aligned} \quad (6)$$

The hazard function $\lambda(d)$, for a discrete probability model, represents the ratio of the probability that the duration is of exactly $d + 1$ periods to the probability that the duration lasts at least d periods. As the following calculation shows, the hazard function for the geometric distribution is a constant.

$$\begin{aligned}
\lambda(d) &= \frac{f(d+1)}{1-F(d)} \\
&= \frac{p^d(1-p)}{1-(1-p^d)} \\
&= 1-p
\end{aligned} \tag{7}$$

Thus, the geometric distribution has the property that information about the duration of phases is of no value in predicting turning points. It is, therefore, the appropriate distribution to use when assessing whether the beginning and ends of major recessions are predictable just on the basis of information about duration of expansions and contractions.

In order to test this hypothesis one compares the estimated distribution function for the geometric distribution $F(d; p)$ with the empirical distribution function $G(d)$. The former is (6) with p replaced by an estimate \hat{p} and the latter is the proportion of observed durations that are less than or equal to d . Here I employ the maximum like likelihood estimator of p viz

$$\hat{p} = \frac{1}{\bar{d}} \tag{8}$$

where, \bar{d} is the sample mean duration.

The Kolmogorov Smirnov test statistic (KS) is used where N is the number of phases observed

$$KS = \left(\sqrt{N}\right) \sup_{d>0} \text{abs}\{F(d; \hat{p}) - G(d)\} \tag{9}$$

Because N is typically a small number one should be cautious about appealing to asymptotic theory to obtain a distribution for KS .¹⁸ Thus, bootstrap procedures will be employed to generate a small sample distribution. The bootstrap is obtained via the following steps:¹⁹

1. 1000 random draws are made, with replacement, from the sample of durations. Each draw contains N durations.
2. At draw i , \hat{p}_i is calculated via (8).
3. $F(d; \hat{p}_i)$ is calculated by inserting \hat{p}_i into (6).
4. The empirical distribution $G_i(d)$ is calculated for the i^{th} draw.
5. The statistic KS_i is calculated for the i th draw by inserting $F(d; \hat{p}_i)$ and $G_i(d)$ into (9).

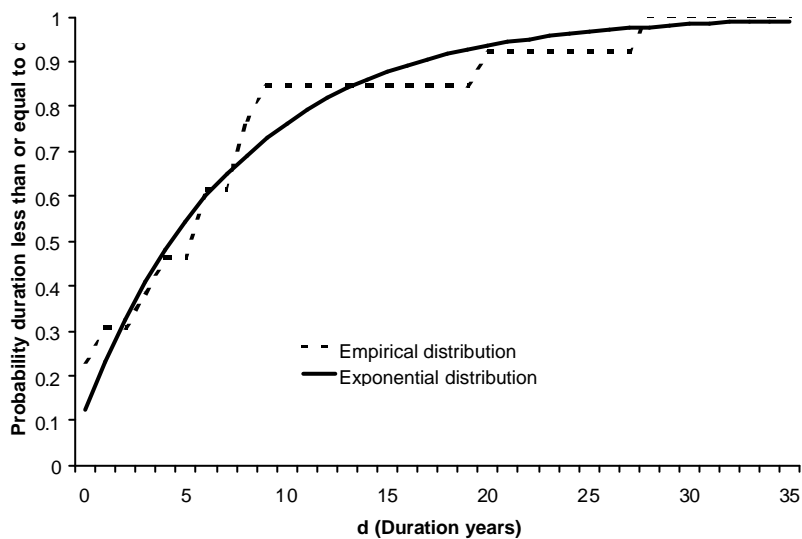
¹⁸The asymptotic distribution is the limit of the sequence of distributions as the number of turning points (N) goes to infinity.

¹⁹For an introduction to the Bootstrap see Efron and Tibshirani (1998)

6. Finally the P-value is calculated as follows $P\text{-value} = (\text{number of } KS_i > KS)/1000$. This provides information on how likely it is that the statistic KS could have arisen randomly. A low P-value would provide evidence that we should reject the hypothesis that turning points are predictable on the basis of the duration of expansion and contraction phases.

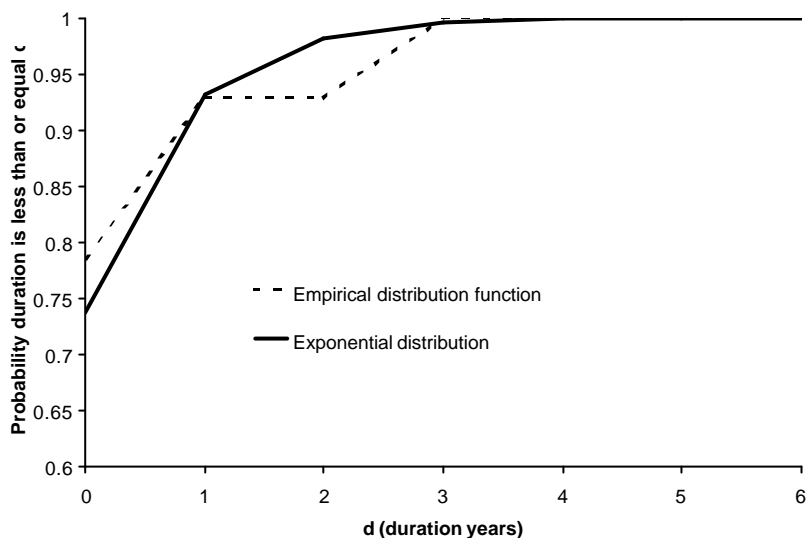
For annual real GDP from 1861 to 2000/01 the KS_e and KS_c statistics for the hypothesis that durations of contractions and expansions are governed by a geometric distribution take the values 0.20 and 0.42 respectively with p-values of 0.57 and 0.98 respectively. Thus the evidence does not reject the hypothesis that durations of expansions and contractions are governed by the exponential distribution. This can be seen by inspecting Figures 15 and 16. Figure 15 shows the empirical distribution function for the duration of expansions together with the geometric distribution with p calibrated to fit that data (ie $p = \hat{p}_e$). Clearly, the geometric distribution fits the data very well and this visual impression is confirmed more formally via the KS_e test statistic reported above. Figure 16 shows comparable information for the durations of contractions. Again the fit of the geometric distribution is seen to be very good a result that is also confirmed more formally by the KS_c statistic discussed earlier.

Figure 15: Confrontation of empirical and geometric distribution for duration of expansions, 1861 to 2000/01



Put less formally the result just obtained supports the hypothesis that major turning points in aggregate economic activity are not predictable on the basis of information about the elapsed duration of an expansion or contraction phase.

Figure 16: Confrontation of empirical and geometric distributions for duration of major contractions, 1861 to 2000/01



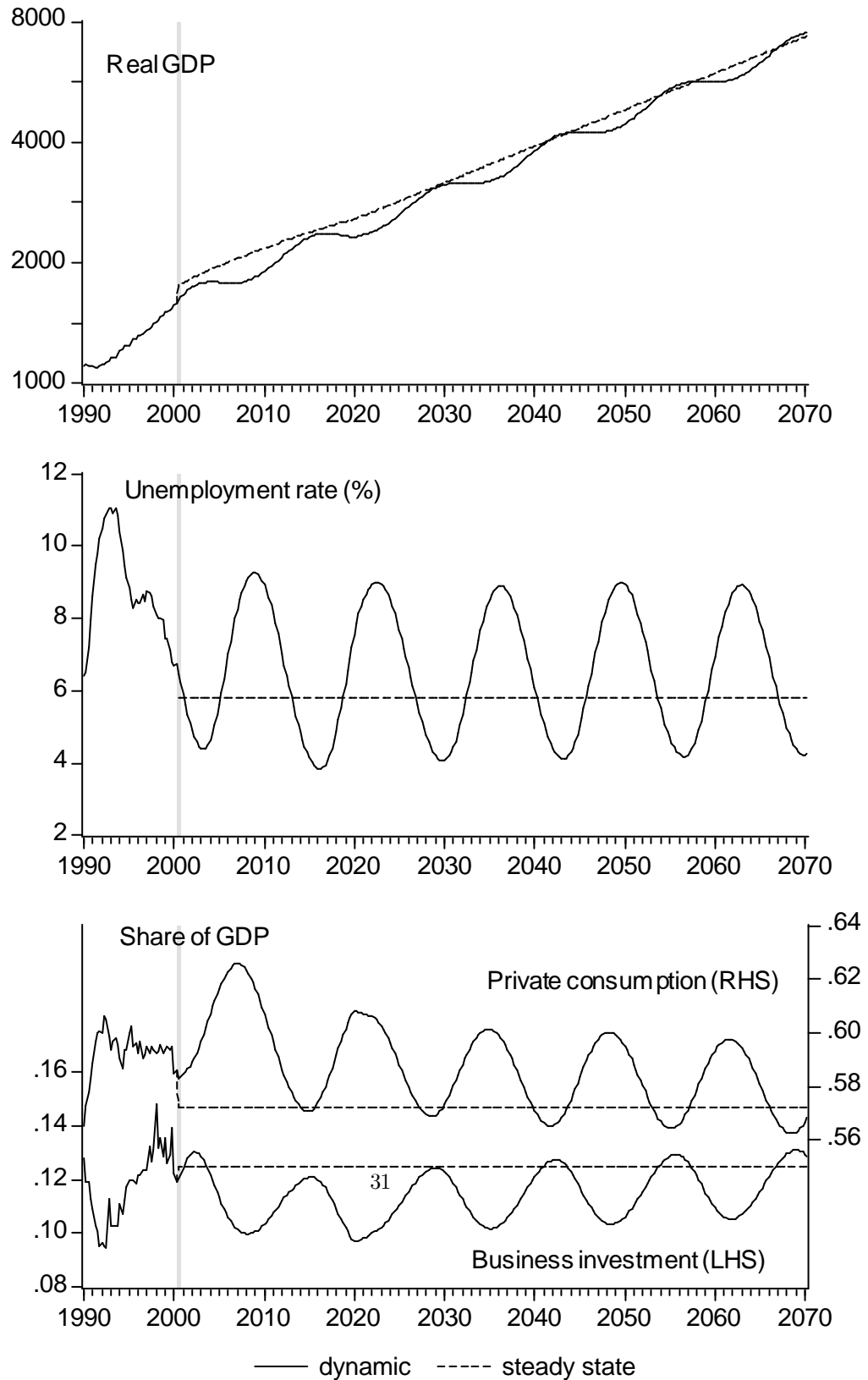
The practical importance of this is two fold. First, it provides a simple basis on which one can select among parametric models according to whether they are consistent with the business cycle features of the data. To be specific parametric models of the Australian economy that imply that one can predict turning points of the business cycle on the basis of the duration of phases should be rejected as inconsistent with the known business cycle facts. One such model is the Treasury Macroeconomic model (TRYM) which Song and Harding (2002) show generates undamped cycles see Figure 17.²⁰ That is TRYM counterfactually suggests that one can predict the business cycle on the basis of information about the duration of the phases of that cycle.

The second practical result is that it allows one to proceed to examine hypotheses regarding changes in the business cycle using the geometric distribution for durations.

There is, however, one complaint that one might make about the approach adopted above, it is that with the calculus rule the event that marks a contraction $\Delta y_t \leq 0$ and the event that marks an expansion $\Delta y_t > 0$ exhaust the set of possible events. Thus one would like to impose the restriction that $p_e = 1 - p_c$. Inspection of the estimates shows that the estimated probability of remaining in an major expansion (\hat{p}_e) is 0.7368 with standard error 0.0688 and the estimated probability of remaining in a contraction (\hat{p}_c) is 0.1226 with standard

²⁰The simulation was performed using the June 2000 release of TRYM with the default reaction functions for fiscal and monetary policy.

Figure 17: TRYM default simulation (June 2000 release): selected variables (1990-2070)



error 0.0127. Thus $\widehat{p}_e + \widehat{p}_c = 0.8694$ which is less than one and one might want to check whether the hypothesis about the predicability of turning points holds when the restriction is imposed

Taking the restriction into account requires that one work with the joint distribution of the duration of expansions and contractions. In order to proceed I assume that the duration of expansions and contractions are independent so that the joint distribution can be written as the product of the marginal distributions viz²¹

$$f(d^e, d^c) = p^{d^e-1} (1-p) p (1-p)^{d^c-1} \quad d = 1, 2, \dots \quad (10)$$

Where d^e and d^c are the durations of expansions and contractions respectively. The joint cumulative distribution function is:

$$\begin{aligned} Pr(D^e \leq d^e, D^c \leq d^c) &\equiv F(d^e, d^c) \\ &= (1 - p^{d^e}) (1 - p^{d^c}) \end{aligned} \quad (11)$$

The log likelihood is

$$l = \ln(p) \left\{ \sum_{i=1}^{N^e} d_i^e + N^c \right\} + \ln(1-p) \left\{ \sum_{j=1}^{N^c} d_j^c + N^e \right\} \quad (12)$$

And, the first order condition for maximizing the log likelihood is

$$0 = \frac{\sum_{i=1}^{N^e} d_i^e + N^c}{p} - \frac{\sum_{j=1}^{N^c} d_j^c + N^e}{1-p} \quad (13)$$

Yielding the restricted maximum likelihood estimator

$$\widetilde{p} = \frac{N^e \overline{d}^e + N^c}{N^e \overline{d}^e + N^c + N^c \overline{d}^c + N^e} \quad (14)$$

where \overline{d}_e and \overline{d}_c are the sample average durations of expansion and contraction phases respectively.

The Kolmogorov Smirnov test statistic (KS_r) for the hypothesis that the joint distribution of expansion and contraction durations is an exponential with common parameter p is

$$KS_r = \sqrt{N^c} * \sup_{d^e > 0} \sup_{d^c > 0} abs [F(d^e, d^c; \widetilde{p}) - G(d^e) G(d^c)] \quad (15)$$

The estimated value of \widetilde{p} is 0.856 with standard error 0.031. And the value of the test statistic KS_r is 2.47 with p-value 0.76. Thus the data do not reject

²¹This is a weak restriction that can be given a foundation in the argument that if the length of an expansion were forecastable on the basis of the length of the preceding contraction then business people and consumers would be able to profit from reajusting their plans. Similarly, the central bank would be able to improve the stability of the economy by adjusting its plan for monetary policy.

the hypothesis that information on elapsed duration of phases is of no use in predicting of turning points. In summary, the results obtained earlier are not altered when one takes into account the fact that the distributions governing expansions and contractions share a common parameter.

One implication of these results is that the process driving GDP and thus the business cycle might be reasonably well approximated by a random walk. I explore this hypothesis using a low order ARMA(p,q) such as (16) below

$$(1 - a_1L - a_2L^2 \dots - a_pL^p) \Delta y_t = \mu^* + (1 - b_1L - b_2L^2 \dots - b_qL^q) \varepsilon_t \quad (16)$$

$$\mu = \frac{\mu^*}{(1 - a_1 - a_2 \dots - a_p)} \quad (17)$$

Where the long run trend growth rate (μ) is related to μ^* by (17), ε_t is a mean zero iid shock with variance σ_ε^2 . The main difficulty with (16) is that with p and q both set at 4 years one obtains imprecise estimates of the coefficients. There are 256 combinations of zero restrictions that one can place on the coefficients of (16). I searched over all these combinations seeking to minimize the Hannan-Quinn () (HQ) and Schwartz () bayesian information criteria (BIC) which are set out in (18) and (19) below

$$HQ = \ln(\sigma_\varepsilon^2) + 2 \frac{\ln(\ln(N))}{N} \{\text{Number of estimated parameters}\} \quad (18)$$

$$BIC = \ln(\sigma_\varepsilon^2) + 2 \frac{\ln(N)}{N} \{\text{Number of estimated parameters}\} \quad (19)$$

In all cases the BIC criteria selected a random walk highlighting both the tendency of BIC to select parsimonious models and the fact that GDP is nearly unpredictable on the basis of past lags of GDP.

A gaussian random walk is summarised by two parameters its mean μ and variance $\sigma_{\Delta y}^2$.²² One can evaluate the Random walk model by studying how well these parameters explain the business cycle features. The sample variance ($\overline{\sigma_{\Delta y}^2}$) of Δy_t is reported in Table 6 together with the sample mean $\overline{\mu}$ for the full sample period and three sub periods. There has been an 83 percent decline in the variance of GDP in the second half of the 20th century over the first half of the 20th century. But the first half of the 20th century seems to be the outlier having a much higher variance than either of the two half centuries by which it is bracketed.. Indeed, the decline in variance between the second halves of the 19th and 20th centuries is only 46 per cent. A similar pattern is seen in terms of average growth rates with the second halves of the 19th and 20th centuries recording average growth rates of 3.46 and 3.75 per cent respectively compared with an incipient 2.58 per cent for the first half of the 20th century.

²²In a gaussian random walk the shocks are drawn from the normal distribution which is fully described by its mean and variance.

Table 6: Evaluation of random walk model for Australian GDP growth rates various periods, 1861-2000.2001

	Full Sample	1861-1900	1901-1950	1951-2001
$10^3 \bar{\sigma}_{\Delta y}^2$	1.30	0.83	2.52	0.45
$100 \bar{\mu}_j$	3.25	3.46	2.58	3.74
$1 - \Phi\left(\frac{-\bar{\mu}_{FS}}{\bar{\sigma}_{\Delta y}}\right)$	0.82	0.87	0.74	0.93
$1 - \Phi\left(\frac{-\bar{\mu}_j}{\bar{\sigma}_{\Delta y}}\right)$	0.82	0.89	0.70	0.96
\tilde{p}	0.856	0.923	0.733	0.949
$E(d^c \mu_{FS}, \sigma_{\Delta y})$	1.23	1.15	1.35	1.07
$E(d^c \mu_j, \sigma_{\Delta y})$	1.23	1.13	1.44	1.04
\bar{d}^c	1.36	1.00	1.63	1.00
$E(d^e \mu_{FS}, \sigma_{\Delta y})$	5.43	7.73	3.86	16.15
$E(d^e \mu_j, \sigma_{\Delta y})$	5.43	8.75	3.29	26.26
\bar{d}^e	8.15	11.50	4.57	18.00

Under the gaussian random walk assumption Δy_t is independently and identically distributed as a normal random variable with mean zero and variance $\sigma_{\Delta y}^2$. Letting $\Phi(x)$ represent the integral of the standard normal from $-\infty$ to x , the quantity $1 - \Phi\left(\frac{-\bar{\mu}}{\bar{\sigma}_{\Delta y}}\right)$ represents an estimate of $Pr(\Delta y_t > 0)$. One can obtain estimates of this quantity by substituting the estimated estimated growth rate for the full sample ($\bar{\mu}_{FS} = 3.25$ per cent per year) into the formulae while using the estimated standard deviation for the sub period yielding the estimates shown in the third row of Table 6. The alternative is to employ the estimate of the mean growth rate for each period $\bar{\mu}_j$ yielding the estimates in the fourth row. Comparing the estimates in the third and fourth row it is evident that it is mainly changes in the variance of Δy_t that have influenced the probability of remaining in expansion over the past one and one half centuries. The comparable estimate of \tilde{p} obtained via the exponential distribution and (14) is reported in the fifth row. As expected the estimates obtained via the geometric distribution are close to those obtained via the gaussian random walk assumption. One way to assess these various estimates is to compute the implied mean duration of phases and compare it with the sample estimates. For this we can use the formulae that under the geometric distribution²³

$$\text{mean duration of contractions} = 1 + \frac{1-p}{p} \quad (20)$$

$$\text{mean duration of expansions} = 1 + \frac{p}{1-p} \quad (21)$$

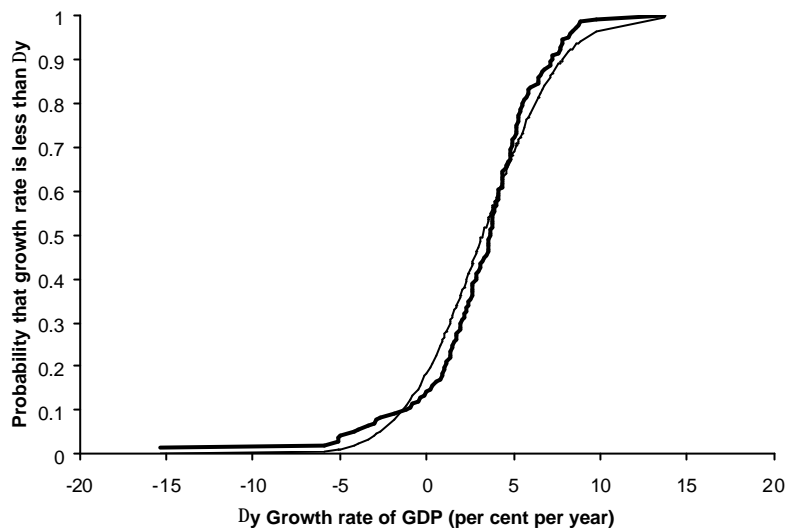
Table 6 reports these quantities for the full sample and various sub periods. Rows 6 to 8 of Table 6 relate to contractions and rows 9 to 11 relate to expansions. The quantities $E(d^c | \mu_{FS}, \sigma_{\Delta y})$ and $E(d^c | \mu_j, \sigma_{\Delta y})$ relate to the mean

²³We must add one back because it is $(d_i - 1)$ that has a geometric distribution.

duration of contractions using the probability of remaining in expansion estimated from the gaussian random walk assumption with the full sample mean and the sub sample means respectively. This is then plugged into the formula for the mean duration from the geometric distribution (20) The quantity \bar{d}^c is the sample mean duration of contractions. Similar notation is used for expansions. It is evident from rows 6 to 8 of Table that the gaussian random walk assumption does a reasonable job of matching the mean durations of contractions. The same cannot be said for expansions where the gaussian random walk assumption results in estimates of contractions that are far too short in most cases. Using the sub period sample mean (row 10) actually makes the estimates of the mean duration of expansions worse in the 19001-1950 period as well the 1951-2001 sub period. This suggests two hypotheses. The first is that it may well have been changes in moments other than the sample mean that explain the differences between the business cycle properties of the three sub periods. The second hypothesis is that the distribution of shocks might be non normal. To investigate this latter possibility Figure plots the empirical distribution of Δy_t for the period 1861 to 2000/01. It is evident that large negative shocks are more evident in the data than is consistent with the normal distribution and large positive shocks are rarer in the data than in the comparable normal distribution. The Kolmogorov Smirnov test statistic for the hypothesis that these two distributions are equal is 0.080 the 5 per cent critical value is calculated using the formula in Bickel and Doksum (1977 p81) as $0.895 / (\sqrt{N} - 0.01 + 0.85/\sqrt{N}) = 0.075$. Thus we can reject the hypothesis that the process driving the growth rate in GDP is exactly a gaussian random walk.

To summarise I advanced the hypothesis that economic theory suggests that turning points are unpredictable on the basis of the elapsed duration of phases. One possibility consistent with this finding is that GDP follows a random walk. I investigated whether a gaussian random walk could fit the data and found that this was not the case. Indeed a Kolmogorov Smirnov test rejects the hypothesis that Δy_t is generated by a normal distribution. It is therefore of some interest to investigate whether the random walk with shocks drawn from the empirical distribution of Δy_t can capture the business cycle features. The results from these simulations are reported in Table 7. Inspection of Table 7 indicates that in most cases the simulated random walk with shocks drawn from the empirical distribution for each sub period matches the business cycle features of the data quite well. The exception to this statement arise because the random walk has some difficulty matching the duration and cumulative movements of contractions in the full sample and the random walk also cannot capture the excess movement in expansions for the 1950/51-2000/01 period. This latter result is particularly important as it suggests that there is some nonlinearity in the propagation mechanism for GDP in the post WWII period. That is it suggests that there is more to the Australian business cycle than it just being a random walk with non normal shocks. Nonetheless the results in Table 7 suggest that the random walk with non normal shocks provides a far better approximation to the business

Figure 18: Confrontation of empirical distribution function and estimated normal distribution functions for growth rate of GDP, 1861-2000/01



cycle than does the assumption of a random walk with normal shocks.

The preceding discussion raises the question of whether the distribution of the shocks Δy_t has changed over time in ways that matter for the business cycle. One way to test this hypothesis is to redo the simulations in Table 7 but with the shocks drawn from the empirical distribution for the full period rather than from the empirical distributions for the sub periods. These simulations are reported in Table 8. It is evident from Table 8 that the distribution of GDP must have changed over the sample period as the random walk with shocks drawn from the empirical distribution of Δy_t for the full period cannot match the business cycle features for any of the sub periods.

6 Conclusions

I have presented a view of the Australian business cycle that is novel in several ways. First, I rely on GDP rather than the reference chronology to measure the business cycle. Second, I have shown that the Australian business cycle in the second half of the 20th century is similar to that experienced in the second half of the 19th century. While annual GDP is somewhat less volatile in the later period it is not dramatically so. The outlier is the first half of the 20th century which exhibited both lower and more volatile growth than the two half centuries by which it is bracketed. Third, I could find little evidence of

Table 7: Confrontation of business cycle characteristics from random walk with draws from empirical distribution, Australian GDP various periods, 1861-2000.2001

	Full sample	1861-1900	1900/01-1949/50	1950/51-2000/01
Duration (years)				
Contractions	1.16 (0.96)	1.08 (0.45)	1.36 (0.95)	1.06 (0.64)
Expansions	7.33 (0.75)	12.91 (0.46)	3.83 (0.87)	17.06 (0.68)
Amplitude (per cent)				
Contractions	-3.81 (0.22)	-2.05 (0.66)	-5.57 (0.16)	-1.23 (0.54)
Expansions	31.03 (0.75)	50.61 (0.54)	18.54 (0.86)	69 (0.70)
Cumulative (per cent)				
Contractions	-2.51 (0.05)	-1.20 (0.73)	-4.82 (0.12)	-0.68 (0.60)
Expansions	210 (0.80)	627 (0.28)	62 (0.77)	1165 (0.64)
Excess (per cent)				
Contractions	0.00 (0.93)	-0.0 (0.82)	-0.01 (0.97)	0.0 (0.87)
Expansions	0.01 (0.84)	0.0 (0.93)	0.01 (0.12)	0.0 (1.00)

Table 8: Confrontation of business cycle characteristics from random walk with shocks drawn from empirical distribution 1961 to 2000/01 1861-2000.2001

	Simulated Mean	1861-1900	1900/01-1949/50	1950/51-2000/01
Duration (years)				
Contractions	1.16	0.09	1.00	0.09
Expansions	7.33	0.97	0.02	1.00
Amplitude (per cent)				
Contractions	-3.81	1.00	0.01	1.00
Expansions	31.03	0.96	0.09	1.00
Cumulative (per cent)				
Contractions	-2.51	1.00	0.00	1.00
Expansions	210	0.96	0.03	1.00
Excess (per cent)				
Contractions	0.00	0.54	0.99	0.54
Expansions	0.01	1.00	0.21	1.00

lengthening expansions and shortening contractions in the quarterly GDP data from 1959.3 to 2001.4. However, I did find some weak evidence that amplitudes of contractions had lessened in recent times. But this evidence is quite weak. Fourth, I confronted the apparent decline in volatility of quarterly GDP over the period 1959.3 to 2001.4 and showed that much of it could be accounted for by a combination of neglected seasonality and improvements in the capacity of the ABS to measure GDP. The fifth way in which the paper is new is that I confronted the notion that the business cycle is periodic and showed that there is no evidence that turning points are predictable on the basis of the elapsed duration of phases. Thus statements frequently encountered in the media that we are in the early or late stages of a recession/expansion have no quantitative basis and should be avoided.

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