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Volatility Transfers between Cycles:

A Theory of Why the "Great Moderation" was more Mirage than Moderation

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Abstract

In this paper we use a New Keynesian model to explain why volatility transfer from high frequency to low frequency cycles can and did occur during the period commonly referred to as the "great moderation". The model suggests that an increase in inflation aversion and/or a reduction to a commitment to output stabilization could have caused this volatility transfer. Together, the empirical and theoretical sections of the paper show that the "great moderation" may have been mostly an illusion, in that lower frequency cycles can be expected to be more volatile, given that there has been no apparent reversal in any of the policy parameters and hence in the volatility found in the low frequency cycles identified by use of time-frequency empirical techniques. In fact, those cycles appear to have increased in power and volatility in both relative and absolute terms.

Keywords: New Keynesian model, business cycles, growth cycles, time-frequency domain, discrete wavelet analysis, Empirical Mode Decomposition.

JEL Classification: C1, E2, E3

DRAFT version - Not to be quoted without permission.

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1 Introduction

"...The reporting of facts—without assuming the data are generated by some probability model—is an important scientific activity. We see no reason for economics to be an exception. " Kydland and Prescott (1990).

The quote above refers to the task of characterising business cycles, and what empirical tools can reveal about the nature of the business cycle. Indeed, although some economists claim that the main task of economics is to test theories, reporting stylized facts based on simple statistical analysis is also an important scientific activity that can then suggest appropriate theories that fit with what is actually observed.

In several recent papers using time-frequency analysis (see Crowley (2010), Aguiar-Contraria and Soares (2011), Rua and da Silva Lopes (2012)), the evidence presented clearly shows how economic growth consists of cyclical fluctuations at various different frequencies, and different components of national income. Although much work needs still to be done in terms of identifying and authenticating the source and drivers behind these different cycles, it is clear that in empirical terms, fluctuations in these cycles appear to wax and wane over time. In particular, in relation to recent growth patterns in both the US and the UK (see Crowley and Hughes Hallett (2014)), it is clear that the "great moderation" largely appeared in higher frequency cycles that were at or shorter than traditional business cycles, while at the same time lower frequency cycles or those at longer than traditional business cycles appear to have become as volatile as the business cycle, and in many cases more volatile.

The idea of a volatility transfer between variables is quite common in policy work. It is usually a consequence of the trade-off between conflicting targets expressed in terms of the variability of those targets rather than their average levels: for example between inflation and output volatility in a Phillips curve setting (Rogoff (1985), Hughes Hallett and Petit (1990)); or in the effects of increasing monetary policy transparency (Demertzis and Hughes Hallett (2007)); or between output or monetary stability vs. exchange rate volatility (Sachs (1983)).

But much less common is the idea of a volatility transfer between different cycles in economic behaviour. In fact, as far as we are aware, there are no formal analyses of how such transfers might arise although recognition that such transfers might take place is implicit in Alesina and Gatti (1995)'s depiction of the trade-off between an economy's political and business cycles, and in Granger (1966)'s characterization of the typical spectral shape before and after an exchange rate is stabilized. Likewise, discussions that volatility transfers could appear between cycles as a result of policy interventions has also been present in the literature for a long time, starting with Wicksell's distinction between a financial cycle and the business cycle (Wicksell (1936), Laidler (1972)). In fact that distinction has a much older tradition than that, having been first developed by Thornton (1802) and then presented in complete form by Joplin (1832). The idea here is that if the rate of interest is held too low, a boom period driven by expanding credit and asset prices will follow. Then, if credit and money are endogenous (or endogenised by policy), a bust will appear when the financial expansion is no longer sustainable or the economy suffers from an adverse shock. At that point, a balance sheet recession will set in as firms, households and banks are obliged to deleverage – triggering a sharp downturn, followed by a period of feeble growth and stubborn unemployment. Typically this type of financial cycle is thought to last 15-20 years, as opposed to the 4-6 years of a business cycle.

Hence, what is missing from the literature is any theoretical analysis of how a volatility transfer between cycles could arise, what the driving variables might be, and whether standard macro-economic models can accommodate or predict such transfers. Given that the financial crash and 2008-12 recession proceeded very much as just described, it is important to resolve these issues and create the basis for a theory of volatility transfers. This is our purpose in this paper.

The "great moderation" period is an interesting episode, in that it also occurs at a time when aversion to inflation among central bankers appears to have been at its most ardent (reflected in, for example, inflation targetting), and when central bank independence appears to have focused monetary policy more in the direction of meeting the objective of price stability rather than output stabilization, which has left fiscal policy as the only way to achieve output stabilization. As a result, it is an interesting exercise to consider what explanations could have given rise to the "great moderation" and whether, in a wider cyclical context, that moderation was in fact more ephemeral than real.

Section 2 presents some of the empirical evidence for a volatility transfer during the great moderation, and then section 3 presents a simple theoretical framework for generating cycle volatility shifts. Section 4 then concludes.

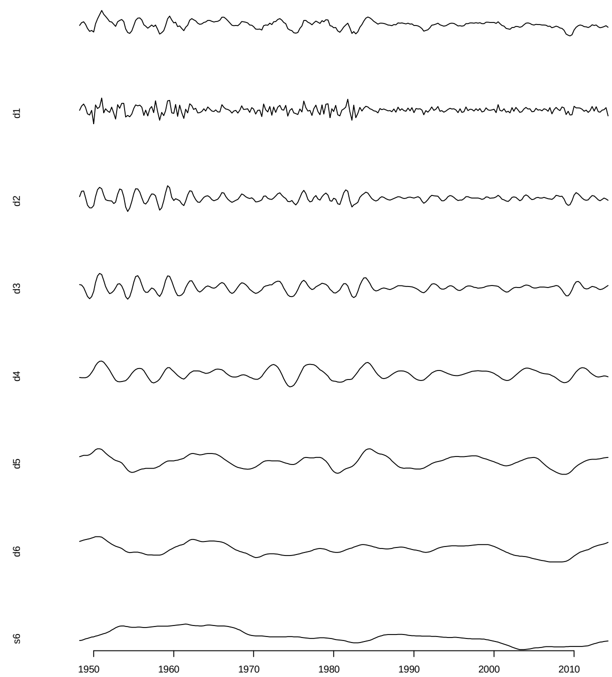

Figure 1: MODWT for log change US real GDP

2 Empirical Evidence for Cycle Volatility Shifts

Wavelet analysis and empirical mode decomposition are relatively recent advances in time-frequency analysis that allow the researcher to decompose any series into frequency components which are embedded in the series. While wavelet analysis does this for specific frequency ranges, empirical mode decomposition separates out the intrinsic modes (or drivers) at specific frequencies which are found to be within the series. More details relating to the wavelet methods used can be found in Crowley and Hughes Hallett (2011), but the updated discrete wavelet decomposition from this paper is shown in figure 1[1].

The first series is the original real GDP plot, and it is quite apparent that US GDP growth appears to become less volatile after the early-1980s, as per the official dating of the commencement of the "great moderation". The next 5 series are the wavelet detail crystals which labelled d1 to d6, which contain the frequency components in the 2 to 4 quarter cycles, 1-2 year cycles, 2-4 year cycles, 4-8 year cycles, 8-16 year cycles, and 16-32 year cycles respectively. The last component labelled s6, which is known as the "smooth", contains any cycles beyond a 16 year cycle, plus any trend in the data.

[1] Here a d4 wavelet was used with MODWT and phase shifting (see Crowley and Hughes Hallett (2014))

What is clear from figure 1 just by visual inspection, is that the volatility in the d1 to d3 crystals (corresponding to cycles between 2 quarters to 4 years) has definitely fallen post the mid-1980s, and indeed, even after the "great recession", the volatility in these series does not appear to have changed much, or has returned to it's pre early-1980s levels. What is less apparent is that the volatility in the longer cycles captured by d4 to d6 have remained at the same levels or has increased slightly. In addition, there appears to be a longer cycle captured by the smooth that has at least the same level of volatility as d6, and d1 to d4 post-1980. This transfer of energy between shorter and longer cycles is difficult to discern by looking at real GDP in the time domain, and is only apparent when viewed through the prism of a time-frequency domain method, such as discrete wavelet analysis.

Another interesting new technique to be recently introduced to economists is emprical mode decomposition (or EMD) - see Crowley (2012) and Crowley and Schildt (2012). Here a purely empirical decomposition is undertaken to extract embedded frequencies as new variables called Intrinsic Mode Functions (IMFs) which then approximate the fluctuations within the series, which of course can have variable frequencies and be highly irregular. Here we show the result of decomposing the US log change real GDP over the same period using a variant of EMD, namely Ensemble EMD (or EEMD)[2].

Figure 2 shows that there are basically 5 IMFs (numbered 1 to 5 down the y axis, and then the residual is plotted at the bottom of the figure). As EEMD claims to extract frequencies of process embedded in any given series, it appears that there are 5 main drivers operating within US real GDP with at least 5 different frequencies. Once again, the message is clear: shorter frequency IMFs 1 and 2 experienced a notable decrease in volatility from the early to mid-1980s onwards, while lower frequency IMFs 3, 4 and 5 experienced at least the same level of volatility, if not more, during the same period.

Thus we see both relative and absolute transfers of volatility to the longer cycles, even if those increases in absolute volatility have been small in some cases. In fact, in more detail, the pattern of volatility has clearly changed over time. The aggregate fluctuations (figure 2, top line) are broadly of the same size over the sample period, but their frequency has changed. The volatility in IMF1, 2, and possibly 3 (but only in the period 1985-2005) has fallen as we supposed; but that in IMF4 and 5 has risen since 1980.

Despite the fact that discrete wavelet analysis and empirical mode decomposition are completely different techniques in the time-frequency domain, both give qualitatively the same answer: the "great moderation" appears to have only been a moderation of high

[2]Here the parameter for noise was 0.2 of the standard deviation, and 800 iterations were done.

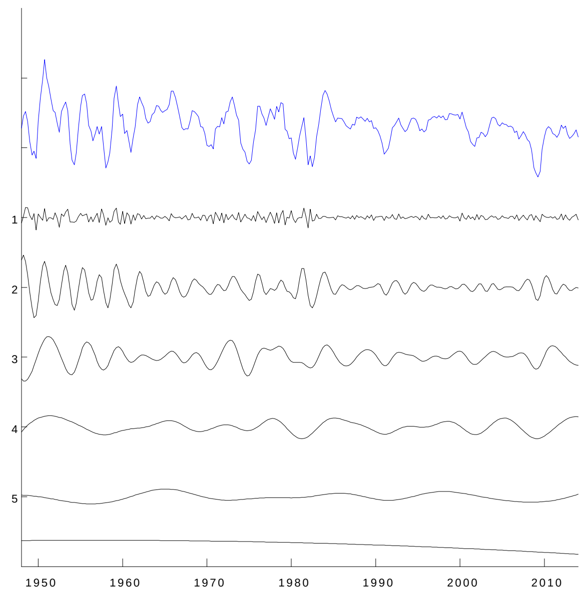

Figure 2: EEMD of log change US real GDP

frequency oscillations in real GDP growth - it did little at all to lower frequency modulations - in fact, if anything it appears to have increased them.

3 Demonstrating Volatility Transfers in a Model

Given the empirical results of the previous section, we now seek to explain these empirically observed phenomena surrounding the volatility of real GDP in the early 1980s onwards, in the context of a theoretical model. We justify our choice of macro model for this exercise as being the most widely-used workhorse of macroeconomic modelling, namely the standard New Keynesian model, here in a variant similar to that used by De Grauwe (2010).

3.1 A Standard New Keynesian Model

Our model is a conventional New Keynesian model, but modified according to De Grauwe (2010) and Acocella, Di Bartolomeo, and Hughes Hallett (2012) to include the possibility of interest rate smoothing by the central bank. Specifically, for aggregate demand we have that:

$$y_t = a_1 E_t y_{t+1} + (1 - a_1) y_{t-1} + a_2 (r_t - E_t \pi_{t+1}) + \varepsilon_t \tag{1}$$

Aggregate supply is given by:

$$\pi_t = b_1 E_t \pi_{t+1} + (1 - b_1) \pi_{t-1} + b_2 y_t + \eta_t \tag{2}$$

The Taylor rule for monetary policy with an additional term for interest rate smoothing is given by:

$$r_t = c_1 (\pi_t - \pi^*) + c_2 y_t + c_3 r_{t-1} + d E_t r_{t+1} + u_t \tag{3}$$

where the variables have their usual interpretations: y_t is the output gap (a value > 0 means above trend), $\pi =$ the rate of inflation, $\pi^* =$ the inflation target, $r_t =$ nominal interest rate (policy rate), E_t denotes an expectation conditioned on the information set available at time t, and ε_t, η_t and u_t are random shocks. The policy parameters are c_1 and c_2, although the policymakers could in principle also choose c_3 and d to control the degree of smoothing. For simplicity, we only consider varying the former, and ignore the possiblity of changes in the latter.

We expect all parameters to be positive except a_2. Also $a_1 > 1$ and $b_1 > 1$, and $c_1 > 1$ (the Taylor principle holds). We further suppose that $a_2 < 0$ and that it is likely to be small in numerical terms (the proportional impact effect of higher real interest rates on the output gap is likely to be quite a lot less than one-for-one); and likewise that $b_2 > 1$ (the impact effect of the output gap on inflation is likely to be greater than one-to-one); and that $c_2 > 0$ is small (by convention, the output gap has a limited influence on central bank monetary policy, except in cases of severe recession). Finally interest smoothing implies $c_3 > 0$, $d > 0$, but small relative to the influence of policy failures $\pi_t - \pi^*$and $y_t \neq 0$.

It is also important to recognise that the assumption that $a_1 > 1$ and $b_1 > 1$ is a consequence of the saddle point condition for the stability of a rational expectations model and hence the existence of a long run equilibrium. Put differently, these two inequalities apply to the forward looking components of the model. They therefore make inflation and output into jump variables that adjust in advance of actual events, driven by private sector anticipations of those events.

3.2 Characteristic roots

The characteristic roots of this system are the following:

$$\lambda_{1,2} = \frac{1 - a_2 b_2 c_1 - a_2 c_2 \pm \sqrt{(a_2 b_2 c_1 - 1)^2 - 4a_1(1 - a_1)}}{2a_1} \tag{4}$$

$$\lambda_{3,4} = \frac{a_2(b_2 c_1 + c_2) - 1 \pm \sqrt{[1 - a_2(b_2 c_1 + c_2)]^2 - 4b_1(a_2 c_2 - 1)^2(b_2 - 1)}}{2b_1(a_2 c_2 - 1)} \tag{5}$$

and

$$\lambda_{5,6} = \frac{1 - a_2 b_2 c_1 - a_2 c_2 \pm \sqrt{[a_2(b_2 c_1 + c_2) - 1]^2 + 4c_2 d}}{2d} \tag{6}$$

There are therefore 3 pairs of roots, of which $\lambda_{1,2}$ and $\lambda_{3,4}$ maybe complex, but $\lambda_{5,6}$ cannot be because the terms under the square root in (6) are always non-negative under our parameter restrictions. Note that we expect $c_2 > 0$ to be small in the great moderation period, and likewise $c_3 > 0$ and $d > 0$ to create the observed stability of monetary policy in that period. But if the economy were to come under pressure, then either $d \to 0$ or $d \to \infty$ are likely as the attempt to smooth the policy path is abandoned (the first case); or as unconventional policy measure such Quantitative Easing (QE) or Outright Monetary Transactions (or OMT) are brought in to over-ride the usual policy choices (the second case). The first strategy would lead explosive behaviour dominating the economy (infinite roots), and the second to zero roots and hence stability in the associated cycles. That of course is the purpose of OMT and, implicitly, of QE.

When do complex roots and cyclical behaviour appear? Using the above expressions $\lambda_{1,2}$ are complex if $4a_1^2 - 4a_1 > [a_2^2 b_2^2 c_1^2 + 1 - 2a_2 b_2 c_1]$. That is, when:

$$a_1 > 0.5 + 0.5\sqrt{1 + (a_2 b_2 c_1 - 1)^2} \tag{7}$$

where the negative root has been ruled out by the requirement that $a_1 > 0$. Consequently, since a_1 has to be positive, and since $a_2 < 0$, $b_2 > 1$ and $c_1 > 1$, the necessary condition is that a_1 is at least greater than $0.5(1 + \sqrt{1}) = 1$. A sufficient condition is then, if a_2 is small, $a_1 > 0.5(1 + \sqrt{2}) = 1.2071$. These conditions are easily satisfied within our parameter restrictions.

Similarly, $\lambda_{3,4}$ are complex if $4b_1(a_2 c_2 - 1)^2(b_2 - 1) > (1 - a_2 b_2 c_1 - a_2 c_2)^2 > 0$; that is, if:

$$b_1 > \frac{(1 - a_2 b_2 c_1 - a_2 c_2)^2}{4(a_2 c_2 - 1)^2(b_2 - 1)} \tag{8}$$

This inequality is easily satisfied: most obviously if a_2 is small and $b_1 > \frac{1}{[4(b_2 - 1)]}$, the option of making the numerator small having been ruled out by $a_2 < 0$.

In summary, it is easy to make $\lambda_{1,2}$ and $\lambda_{3,4}$ complex - a_1 has to be a little larger than 1 (> 1.2 will suffice if a_2 is small and negative), and ensure that $b_1 > \frac{1}{[4(b_2-1)]}$ where $b_2 > 1$.

3.3 The impact of policy on cycles

What we now need to show is how the eigenvalues, and hence the cycles that they represent, change with the policy parameters. We demonstrate this by looking at the partial derivatives with respect to the main policy parameters, c_1 and c_2, for each of the cycles represented by the eigenvalues $\lambda_{1,2}$ and $\lambda_{3,4}$.

a) First we look at the $\lambda_{1,2}$ cycle. Using the absolute values of the roots from equation 4 above, we have (after taking the positive root to get the required absolute value):

$$|\lambda_{1,2}| = \left[\frac{-(a_2b_2c_1-1)^2 - 4(a_1-1)a_1 + [1-a_2(b_2c_1+c_2)]^2}{4a_1^2}\right]^{0.5} \tag{9}$$

Hence:

$$\begin{aligned}\frac{\partial|\lambda_{1,2}|}{\partial c_1} &= \left[\frac{-(a_2b_2c_1-1)^2 + 4(a_1-1)a_1 + [1-a_2(b_2c_1+c_2)]^2}{4a_1^2}\right]^{0.5} \\ &\cdot\left\{\frac{-a_2b_2(a_2b_2c_1-1) + [1+a_2(b_2c_1+c_2)]\,a_2b_2}{4a_1^2}\right\} \\ &= \frac{a_2b_2(2+a_2c_2)}{2a_1\sqrt{-(a_2b_2c_1-1)^2 + 4(a_1-1)a_1 + [1-a_2(b_2c_1+c_2)]^2}} \\ &= \frac{a_2b_2(2+a_2c_2)}{2a_1\sqrt{4(a_1-1)a_1 + (a_2c_2)^2 - 2a_2c_2(1-a_2b_2c_1)}} < 0\end{aligned} \tag{10}$$

as the term under the square root is inevitably positive because a_2 is negative, and also because a_2 is small enough to make $2 + a_2c_2 > 0$.

Likewise, for the c_2 parameter:

$$\begin{aligned}\frac{\partial|\lambda_{1,2}|}{\partial c_2} &= \left[\frac{-(a_2b_2c_1-1)^2 + 4(a_1-1)a_1 + [1-a_2(b_2c_1+c_2)]^2}{4a_1^2}\right]^{0.5} \\ &\cdot\left[\frac{[1-a_2(b_2c_1+c_1)][-a_2]}{4a_1^2}\right]\end{aligned}$$

$$= \frac{-a_2\left[1-a_2(b_2c_1+c_2)\right]}{2a_1\sqrt{-(a_2b_2c_1-1)^2+4(a_1-1)a_1+\left[1-a_2(b_2c_1+c_2)\right]^2}} > 0 \tag{11}$$

since the square root term is again positive as in (10) and a_2 is small. Thus increasing inflation aversion, and therefore higher c_1, as was evident during the "great moderation" will decrease the size of the $\lambda_{1,2}$ cycles. Similarly, a decrease in the attention paid to output stabilization and growth, and therefore a lower c_2, again evident in the "great moderation", will also decrease the size of the $\lambda_{1,2}$ cycles.

b) Next we look at the policy impact on the $\lambda_{3,4}$ cycle.

$$|\lambda_{3,4}| = \left[\frac{-(1-a_2(b_2c_1+c_2))^2+4b_1(b_2-1)(a_2c_2-1)^2a_1+\left[1-a_2(b_2c_1+c_2)\right]^2}{4b_1^2(a_2c_2-1)^2}\right]^{0.5} \tag{12}$$

$$= \left[\frac{b_2-1}{b_1}\right]^{0.5} \tag{13}$$

So the partial derivatives of $|\lambda_{3,4}|$ with respect to c_1 and c_2 are both zero, as can be checked directly.

In other words, there will always be a shift in relative power to/from $\lambda_{1,2}$, relative to $\lambda_{3,4}$, when c_1 and/or c_2 change. In fact relative power will pass from $\lambda_{1,2}$ to $\lambda_{3,4}$ when either c_1 increases or c_2 falls, as happened in the great moderation episode. The implication is that the great moderation may not have been a "moderation" in a cyclical sense at all; but a situation in which cyclical power shifted from the business cycle lengths (the sole focus of attention in previous studies) to longer cycles which lie outside the business cycle frequency bandwidth. Thus, if we focus on business cycle lengths, it will appear that there has been a moderation – whereas in reality the moderation is a mirage, with cyclical activity shifting to the longer "financial" cycles, as Wicksell predicted. This means that cyclical instability is still present and recessions will still appear, although they may be less frequent because longer cycles are more dominant, and take longer to materialize, but they might be more severe when they do appear.

3.4 Cyclical Shifts and the "Great Moderation"

Next we focus on the length of the cycles and the mechanism which could have been at work to generate the shift in cyclical power which gave rise to the "great moderation".

To see which root dominates to start with, suppose $\lambda_{1,2}$ represents the business cycle. This cycle will dominate the economy before the moderation or change in policy parameters if $|\lambda_{1,2}| > |\lambda_{3,4}|$; that is, if:

$$\frac{4(a_1-1)a_1-(a_2b_2c_1-1)^2+[1-a_2(b_2c_1+c_2)]^2}{4a_1^2} = \frac{4a_1(a_1-1)+a_2c_2[a_2c_2-2b_2c_2+1]}{4a_1^2} \tag{14}$$

$$> \frac{b_2-1}{b_1} \tag{15}$$

This inequality is easily satisfied; for example, when $a_2 < 0$ is relatively small (as we expect), $a_1 > 1$, and b_1 relatively large (meaning that the main issue is inflation persistence); and/or when $b_2 \longrightarrow 1$, as in the Rogoff and Barro-Gordon applications[3]. Then when c_1 increases or c_2 falls, the power of the business and longer cycles swap around and the mirage of a great moderation follows.

The cycle lengths for $\lambda_{1,2}$ and $\lambda_{3,4}$ are given by $2\pi/\theta$, where $cos\theta = \alpha/r$ defines θ for roots written as $\lambda = \alpha \pm i\beta$ with $i = \sqrt{-1}$ and $r = |\lambda| = \sqrt{\alpha^2+\beta^2}$. Thus long cycle lengths correspond to small values of $\theta(\rightarrow 0)$, because then $\cos\theta \approx 1$, $\alpha \approx r$, and $\beta \approx 0$. For our story so far, we want the "great moderation" to appear when c_1 increases and/or c_2 decreases, implying that power passes from $\lambda_{1,2}$ to the longer cycles represented by $\lambda_{3,4}$ when there is increasing inflation aversion. But we already have that:

$$\beta_{3,4}^2 = \frac{4b_1(b_2-1)(a_2c_2-1)^2-(1-a_2(b_2c_1+c_2))^2}{4b_1^2(a_2c_2-1)^2} \tag{16}$$

so that:

$$\frac{\partial\beta_{3,4}^2}{\partial c_1} = \frac{[1-a_2(b_2c_1+c_2)](-a_2b_2)}{2b_1^2(a_2c_2-1)^2} > 0 \tag{17}$$

This implies that the imaginary part of these two roots is small if $a_2 < 0$, b_1 large, and $b_2 \rightarrow 1$ from above. In short, exactly those parameter values required in our explanation so far. In that case, $\lambda_{3,4}$ supplies the longer cycles. However, increasing inflation aversion (c_1 larger) will shorten the cycle length somewhat – only by a limited amount if a_2 is small and b_1 large (as in our story so far), meaning that $\lambda_{3,4}$ is likely to remain the longer cycle.

Against that:

[3] See Barro and Gordon (1983) and Rogoff (1985).

$$\frac{\partial\beta_{3,4}^2}{\partial c_2} = \frac{8b_1(b_2-1)(a_2c_2-1)a_2 - 2[1-a_2(b_2c_1+c_2)](-a_2)}{4b_1^2(a_2c_2-1)^2} - \frac{[4b_1(b_2-1)(a_2c_2-1)^2 - [1-a_2(b_2c_1+c_2)]^2[8b_1(a_2c_2-1)a_2]}{16b_1^4(a_2c_2-1)^4} \tag{18}$$

$$= \frac{-a_2^2b_2c_1(1-a_2(b_2c_1+c_2))}{2b_1^2(a_2c_2-1)^3} \tag{19}$$

The expression in (18) is unambiguously positive under our parameter restrictions since $a_2 < 0$. Combining this result with (16) implies that if in the great moderation period c_1 became larger and c_2 was reduced – as is commonly supposed since policies became increasingly focused on inflation control – the effect on the cycle length of $\lambda_{3,4}$ is broadly neutral: raising c_1 shortens the cycle length, but reducing c_2 lengthens it. In practice it may not be quite so simple since c_1 may have been increased more than c_2 was reduced, in which case there would have been a slight shortening[4]. But the net effect would be very small since both changes are proportional to a_2, which is small.

To complete this part of the explanation, the corresponding results for the $\lambda_{1,2}$ cycle are:

$$\beta_{1,2}^2 = \frac{4a_1(a_1-1)-(a_2b_2c_1-1)^2}{4a_1^2} \tag{20}$$

Hence the imaginary part of these roots is larger than the imaginary part of $\lambda_{3,4}$, and the associated cycle length shorter, unless $a_1 < b_2$ (unlikely) and a_2 is very small. However, the cycle length becomes longer as c_1 increases. But the effect is small if a_1 is not much above 1 and a_2 is small; and the decreases in c_2 have no effect. In fact the partial derivatives with respect to c_1 and c_2 are:

$$\frac{\partial\beta_{1,2}^2}{\partial c_1} = \frac{-(a_2b_2c_1-1)a_2b_2}{2a_1^2} < 0 \tag{21}$$

and:

$$\frac{\partial\beta_{1,2}^2}{\partial c_2} = 0 \tag{22}$$

So, overall, any extension in the cycle length of $\lambda_{1,2}$ will be limited compared to contractions in the length of the $\lambda_{3,4}$ cycle. Thus the dominance of $\lambda_{3,4}$ as the longer cycle is not threatened.

[4] Also because (18) may be smaller than (16) in absolute value.

The upshot of these results is that changes in the policy parameters associated with the great moderation would have had little effect on the cycle lengths, and our proposition that the main effect would be to reduce the power of the shorter/business cycles at the cost of increasing the power and stronger recessions in the longer cycles, goes through[5].

4 Conclusions

In this paper we first note the stylized fact obtained from empirical time-frequency analysis that the "great moderation" appears to have been caused by a shift in cyclical volatility from shorter cycles in economic growth to longer cycles. Then we use a standard New Keynesian model to show how this stylized fact could have occurred. Our findings are that, indeed, the empirically observed shift in volatility from shorter to longer cycles in economic activity could have been prompted by an increase in inflation aversion, and/or reduction in output stabilization.

Taken together, the theoretical underpinnings for the empirically observed phenomena of shifting volatility in real GDP growth suggest that the "great moderation" was not so "great" after all. It was concentrated only in higher frequency cycle components of growth, and was offset by constant or increasing volatility in lower frequency cycle components. In fact both the model and the empirical evidence tend to suggest that this volatility transfer has not been reversed, and so lower frequency cycles might well continue to be more volatile in the future. If that is the case, our analysis predicts less frequent but larger boom and crash cycles than in the past.

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[5] The results above assume that r does not change. An appendix to the paper explains that this is likely to be a second order effect and have little impact on our results so far.

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A Appendix

There is one caveat here: the results above for changes in $\lambda_{1,2}$ are not quite correct since r will change as well, changing the ratio β/r. Only $\lambda_{1,2}$ matters here since we discovered above that $\lambda_{3,4}$ was unaffected by changes in c_1 or c_2 . Since we know $|\lambda_{1,2}|$ is reduced when c_2 decreases, the modification in this case is minimal since the decrease in cycle length from this source counteracts the increase derived from an increase in c_1 (which is in itself small enough not to change anything when a_2 is small if $a_1 > 0.25$, which itself is easily checked and well within our permitted parameter range).

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