Is Alan Greenspan a Bayesian?

Luke Willard

OECD, France

Abstract  Alan Greenspan speculated about an increase in productivity growth in the mid-1990s well before standard classical (or frequentist) statistical tests suggested a change. I explore whether Bayesian methods, which are potentially better suited to the problem faced by decision makers, can help in understanding Greenspan’s behavior. Using Bayesian techniques, the evidence for a structural change does seem to accumulate sooner than with a classical approach. There is evidence of substantial uncertainty about the extent of the productivity increase, which is unlikely to be captured by simple classical methods. The results suggest that Bayesian methods are useful for examining whether structural change has occurred.

Keywords: Productivity, structural change

JEL Classification: C10, E58, O4

1. Introduction

Detecting structural change can be difficult, especially in real time. A good example of an early detection of structural change can be seen in Alan Greenspan’s early identification of an increase in U.S. productivity growth in the mid-1990s. As early as the Federal Open Market Committee (FOMC) meeting in December 1995, Greenspan argued that there were reasons to think that productivity growth may have increased. Yet in 1997, the Federal Reserve staff and most of the other FOMC members were still not convinced. Based on classical tests at the 10 per cent significance level, no increase in productivity growth would have been detected until 2001. However subsequent productivity data shows a marked increase with annualized growth of around 1.5 per cent over the early 1990s increasing to around 2.4 per cent in the late 1990s. While there is substantial volatility in the data, it points to productivity growth being somewhat higher in the late 1990s and early 2000s than it had been over the previous twenty years (Figure 1).

Classical statistics provided weak evidence of a structural break until data for this decade (i.e. data after 2000) is included. However these classical approaches can be problematic. The standard criterion of rejecting the null of no structural change at the 5 percent significance level may lead a decision maker not incorporating new information fast enough, especially if there is uncertainty about the parameter estimates. This suggests a classical test of the null hypothesis of no structural change is too simple to be a reasonable decision rule.

I explore how a Classicist and a Bayesian may have interpreted the data and the speed at which they would have changed their views about the economy. By examining how various classical and Bayesian statistics evolved as I add more data to the end of the sample, a sense
can be gained of how a decision maker’s views may have changed through time. It will be seen that there is stronger evidence of a structural break using Bayesian (than classical) methods. Also there is some evidence that over time it became more evident that a productivity growth increase had occurred. Greenspan’s speculation about whether a productivity growth increase had occurred is consistent with Greenspan being concerned about the likelihood of a substantial increase in productivity growth. Concern about the likelihood of a substantial increase in productivity growth would be reasonable for a Bayesian decision maker who is interested in the likelihood of various states of nature and the consequences of his actions in those states.

Next is an outline of my methods. This is followed by a more detailed discussion of the statistics calculated together with the results. Finally conclusions are presented. This paper can only at best approximate a real time decision making exercise as I will be using the final vintage of data (as at 2005) rather than data as it was available at the time.

2. Method

Models are estimated that are variations on the following Baseline Model:

\[ p_t = \mu_R + \sum_{i=0}^{3} \theta_i y_{t-i} + \epsilon_t, \epsilon_t \sim N(0, \sigma^2) \]  

where \( p \) is the quarterly growth rate (in percent) in output per hour in the business sector, \( y \) is the growth rate in GDP and the intercept term, \( \mu \), is allowed to change over time thereby changing productivity growth. The sample is from Q1 1975 to Q2 2005. I calculate the following statistics as indicators of the likelihood that a productivity growth increase has occurred: (a) the Andrews (1993) classical test for a structural break over the middle 70% of the sample, (b) the posterior probability that the intercept shifted resulting in an economically significant increase in productivity growth (c) evidence from a regime switching model which allows for variation in the coefficients and the variance and (d) a Kalman filter estimate of the intercept term (which allows incremental productivity growth change through time).

The focus is primarily on the time when Greenspan would have concluded that there had been a structural break (rather than the date of the structural break) and some of the statistics are calculated iteratively. For example, I calculate the Andrew’s statistic using a sample up to Q1 1990 and then again for a sample up to Q2 1990 etc (adding one observation at a time). The robustness of some of the results to a number of alternative specifications are also examined. One model (Model 1) involves only including contemporaneous growth as a control. Another model (Model 2) instead has four lags of GDP growth, productivity growth, GDP price deflator growth and profits/GDP as controls. The latter specification is motivated by references suggesting that Greenspan looked at inflation and profits data in assessing whether there had been a productivity growth improvement (see Blinder and Reis, 2005, and Woodward, 2000).
3. Empirical Results

3.1 Andrews’ Statistic

Figure 2 indicates the Andrews’ statistic for the Baseline Model and Models 1 and 2 with data up to the sample period indicated on the x axis. The test is over the middle 70 per cent of the sample. So, for example, the test using the sample from Q1 1975 to Q4 1999 tests for breaks from Q3 1978 to Q1 1996. Based on Model 1 the null is rejected at the 5 per cent level using data from Q1 1975 to Q3 1992 and Q1 1975 to Q4 1992 (with the F tests suggesting the break occurred in 1986). The null is also rejected using data from Q1 1975 up to Q1 2003 or latter.

Based on the results from the Baseline Model and Model 1, there is weak evidence of a structural break in the early to mid-1990s using classical methods. Based on the Baseline Model and Model 1 (with less controls), I do not reject the null of no structural break at the 5 percent significance level if data only up to 2001 is included. Model 2 (with more controls) provides stronger evidence of a structural break. This is supportive of the view that Greenspan was looking at a variety of data when concluding that there was a structural break.

However the evidence does not seem completely consistent with the story that Greenspan was looking at variables like profitability and inflation when deciding whether a break had occurred. If 1995 was the period of the structural break and profitability and inflation were important in Greenspan’s decision, then it would be reasonable to expect that the Andrews’ statistic for Model 2 would be significant from around 1999. (This is roughly when 1995 becomes part of the middle 70 percent of the sample.) While the statistic for Model 2 was significant at the 5 percent level in 1999, the statistic was substantially higher earlier in the sample. This suggests that statistically it would have been more compelling to have argued that there was a structural break based on the data available around Q1 1991 than to have argued there was a structural break based on the data available in 2000. Moreover using the whole sample of data, a break around 1986 is more likely than one around 1995 (in the sense that the F statistic is higher for the 1986 break than the 1995 one).

Looking at the raw data in Figure 1, these results do not seem implausible. Though it is difficult to discern because of the volatility in the data, it looks as if there was plausibly a slow-down in productivity growth around 1986 and that there was not a persistent increase in productivity growth until around 1996.

3.2 Posterior Mass of a Structural Change

Next I turn to the potentially more promising Bayesian methods. I calculate the posterior probability of an economically significant shift in productivity growth using Bayesian methods. This seems a more relevant statistic to focus on if there is concern that uncertainty may make classical methods unlikely to reject the null hypothesis of no productivity change. Specifically for all three models, the posterior probability of an intercept shift equivalent to an increase in productivity growth of 0.25 percentage points per quarter or more since 1995 (around the time Greenspan started speculating about a productivity improvement) is calculated. Such an improvement translates into an annual increase of productivity growth of over 1 percentage point – an economically significant improvement. Two priors are used for the analysis, both with the same prior for the variance with prior 1 having more concentrated
beliefs about the coefficients around zero (compared to prior 2). Most of the mass on the coefficients lies between negative two and two. To give a sense of the dispersion of the priors Table 1 reports the probability of quarterly growth increase of at least 0.25 percentage points in 1995 in the dummy variable. Figures 3a and 3b report the prior for the variance and the coefficients under the two priors (the prior for the variance is the same for both priors).

Figure 4 reports the posterior probability of at least a 0.25 percentage points increase in productivity growth in 1995 for different models and priors (i.e. for a shift in the dummy constant in 1995). Regardless of which model is estimated (Baseline, Model 1 or Model 2), the results are similar. Also regardless of whether prior 1 or prior 2 is used and whether all parameters are allowed to change or just the constant term, the results are fairly similar. Specifically the posterior mass increases as more data is obtained and after about 1996 the posterior mass tends to be around 0.45 or higher. This seems to be sufficient grounds for Greenspan to seriously consider a productivity growth increase when assessing policy. Moreover these posterior probabilities within about one or two years are higher than the prior probabilities (see Table 1 and Figure 4), suggesting that the data is adding to the evidence of a structural change. Figure 5 presents the posterior cumulative density function for the dummy coefficient, where the median is indicated by the y co-ordinate when the x co-ordinate is 0.5. The figure provides further evidence that as more data is added to the sample the likelihood of a substantial productivity growth pick-up in 1995 increases (though it also suggests substantial decreases in growth were also more likely).

Overall the results from this section suggest there is some evidence of a structural break soon after 1995 consistent with Greenspan’s behavior and that the evidence for a productivity increase strengthened over time. This suggests Bayesian methods would have provided evidence of a structural break sooner than simple classical hypothesis testing of a null of no productivity growth.

3.3 Structural Change with Markov Switching

Next, I use a Bayesian Markov switching model (using the methods of Chapter 9 of Kim and Nelson, 1999) to model a variant of the productivity growth regression, equation (1). This Markov switching model is a more general model than the models considered previously, as it allows all coefficients to change and the variance to change. Allowing the variance to change has the advantage of being able to potentially capture the effect of “the Great Moderation” (the moderation in macroeconomic volatility since the mid-1980s noted by Bernanke, 2004, and Blanchard and Simon, 2001).

More specifically, it is assumed that there is one structural change in the variance and one in the coefficients which are each described by a Markov switching model into an absorbing state. If there was no structural change, the dummy coefficients should be close to zero while if there is productivity growth improvement there should be an increase in the dummy variable. Table 2 and Figures 6a and 6b report key statistics from this modeling approach using relatively diffuse and non-diffuse priors on the Baseline Model for the whole sample. Prior A assumes coefficients are distributed Normal (0,2I) and prior B Normal (0,0.5I), so the probabilities of a productivity growth increase of at least 0.25 percentage points or more are around 0.45 and 0.31. It also reports results for subsamples using prior A. (An appendix, which is available from the author, provides evidence about the model converging.)
Using this general approach and the whole sample, there is evidence of a substantial increase in productivity growth (Table 2). The results using the whole sample suggest it is highly likely that there has been a significant productivity growth increase. Though the productivity is most likely to have occurred around the turn of the century, there is a reasonable probability that it occurred some time during the late 1990s (Figure 6a).

The results using subsamples provide more modest, though not insubstantial, evidence of a productivity growth increase. The models put most of the probability of a structural change in the last few periods of the sample. While a decision maker would be cautious about putting excessive weight on just a few observations, the estimates do suggest that structural change could be occurring and that a rational policy maker would want to consider the effects of such a change in setting policy. Similar to Figures 4 and 5, the results in Table 2 and Figure 7 indicate that the distribution of the dummy coefficient is fairly disperse. These suggest that a decision maker would want to consider scenarios like a productivity growth increase (even though classical tests could not reject there being no productivity increase). Somewhat differently to the results in Figures 4 and 5, the Markov model results suggest that by the end of 1995 there is reasonable evidence that a productivity increase has occurred. The evidence for a productivity increase lessens over the coming few years but when the whole sample is included the evidence is extremely strong.

3.4 Kalman Filter

Finally I employ an alternative modeling strategy which allows for more than one structural change. This is in part motivated by the results for the Markov model. In the Markov model there was evidence that as more data was added to the subsamples the estimated date of the structural break changed. This could be indicative of there being more than one structural break. Specifically the regressions are estimated using a Kalman filter, allowing the intercept term, $\mu$, to evolve incrementally over time (as a first order autoregressive process similar to Hamilton, 1994, Ch. 13). The Kalman filter can be interpreted as Bayesian as it involves updating forecasts of the state based on prior information and data. Using the Kalman filter, there is evidence of productivity growth generally increasing over the mid and late 1990s. However the intercept was rising from a relatively low level and did not approach the levels of the early 1990s until around 2000 (Figure 8). It suggests that a productivity increase may not have occurred until after the period Greenspan started speculating about it. Even given this, the volatility of the estimates and the sensitivity of the results to the model estimated suggest that a decision maker would need to seriously consider a wide range of productivity scenarios when deciding policy.

4. Summary and Conclusions

This paper explores the insights that can be gained from classical and Bayesian methods of detecting structural change, through an investigation of the productivity growth increase of the 1990s. Using simple models (where only the constant coefficient changes) and classical methods I don’t detect a structural break until very late (around 2001). This may be because the 5 or 1 percent significance level is excessively stringent, especially in light of parameter uncertainty. Also the late detection of the break is in part because the Andrew’s test only tests for breaks in the middle 70 per cent of the sample, so a test for a structural break in 1995
requires data up to 1998 or latter. A Bayesian approach potentially addresses these limitations.

Overall Bayesian methods seem to provide stronger and earlier evidence of a productivity increase (than classical methods). They also suggest that there is substantial uncertainty about the size of the structural change. This suggests that it would be reasonable for Greenspan to be also looking at additional evidence, such as disaggregated profitability and price data (as suggested by Woodward, 2000) to decide the likelihood that a shift had occurred and the likely size of the shift. He may have also employed prior beliefs about what was reasonable and discounted the data which was inconsistent with his beliefs. If he behaved in this way, he can be viewed as behaving like a Bayesian. More importantly for the purposes of this paper, Greenspan’s early call of a productivity growth increase can be viewed as an attempt to interpret the likelihood of particular scenarios. Even though the methods I have employed do not provide overwhelming evidence of a structural break in 1995, they do suggest during the late 1990s there was reasonable probability that it occurred. A Bayesian decision making process would have used this and other information (including priors) to evaluate the likelihood of a structural break and would be more sensitive to the data than simply using a classical hypothesis test of no change as a decision rule. In this sense also Greenspan’s actions can be viewed as being consistent with him being a Bayesian.

Endnotes

* Economics Department, Organisation for Economic Co-operation and Development, 2 rue André-Pascal, 75775 Paris CEDEX 16, France, Email: lukewillard@hotmail.com. The author would like to thank Kirdan Lees, Ashley Miller, Tamas Papp, Ricardo Reis, Hyun Shin and others for suggestions and especially Alan Blinder and Chris Sims for guidance and suggestions throughout this project. Financial assistance was provided by the Institute for Humane Studies. All errors are the author’s and the views do not necessarily reflect those of the OECD.

1. This summary of events is based on Blinder and Reis (2005), though Greenspan may have recognized the potential for increased productivity from information technology and reduced price pressures from globalization as early as 1988 (see Friedman, 2006). A number of papers including Jorgenson et al. (2008) and Oliner et al. (2007) examine issues like the source of the productivity increase.

2. Nordhaus (2001) notes that it is problematic assessing productivity growth without taking account of the stage of the business cycle. However even comparing annualized productivity growth from peak to peak over the last two cycles there has been a moderate increase from 2.0 per cent to 2.3 percent.

3. As an aside, note that one possible explanation for why there might be a rise in average productivity growth but no change in the coefficients of a model such as equation (1) below is because the average values of the right hand side variables have changed thereby contributing to an increase in productivity growth. However using a Blinder-Oaxaca decomposition for a structural change in 1995 where all parameters change in (1) I find that the change in the right hand side variables would have contributed to a slowing in productivity growth (see Blinder, 1973, and Oaxaca, 1973). Also another possibility is that
productivity growth rises because of changes in the slope parameters, a case considered in the Markov model below.

4. There is an existing literature on testing for a structural change in labor productivity, estimating its date and related issues from a classical perspective, which Hansen (2001) summarizes.

5. Potentially classical methods can be used to provide more information useful to the decision maker. For example, by testing the null of a one percent productivity increase, an econometrician can get a sense of how likely it is a productivity increase occurred. However for the rest of this paper the results of using a classical test of no change and various Bayesian methods will be compared.

6. The variables used are output per hour of all persons in the business sector, GDP, profits after tax of the corporate sector and the chain price index of GDP. All data are from Datastream, are seasonally adjusted and are for the US. As a robustness check I have conducted some of the analysis using the true real time data available at the end of 1996 and get consistent results.

7. These Andrews (F sup) statistics are calculated using robust standard errors so are plausibly robust to time variation in volatility. Using a shorter sample (from 1985) also leads to little evidence of a structural change before the sample is extended to around 2001 (at least for the Baseline Model and Model 1).

8. If all the coefficients are allowed to change at the structural break there is strong evidence of a break even when the sample is only up to Q1 1990 using the Baseline Model. Again it is difficult to reconcile this result with Greenspan’s call in 1995 that there may have been a structural break – it suggests that if anything he should have been arguing this far earlier.

9. An alternative explanation for the high F statistic for 1986 relative to 1995 is that it is more likely that a structural break can be detected in the middle of the sample than toward the ends. Analysis using the Andrews test for an end of sample break (using the sum of squared residuals and described by Fair (2004)) on the Baseline Model does not reject the null of no structural break in 1995 (at the 5 percent significance level) whether the whole sample of data is used or only a subsample.

10. As noted in footnote 5, more sophisticated classical methods may also provide evidence of a structural break earlier.

11. There is some evidence of this. The Bayesian information criterion (see p. 100 of Lancaster, 2004) comparing a structural break in 1995 with no structural break provides more evidence of a structural break after 1996. However it only falls below 1 (and hence favors the model with a structural break) after 2000. While this is a Bayesian statistic, it would not necessarily determine a Bayesian policy maker’s actions because (a) it does not take account of the policy maker’s priors and (b) it is calculated using the maximized likelihoods. The latter means that it is unlikely to adequately capture the effects of parameter uncertainty, like the classical statistics considered above.
12. In the notation of Bauwens et al. (1999), prior 1 is normal inverted gamma-2 \((0,2I,5,5)\) and prior 2 is \((0,0.5I,5,5)\). The priors on the variance were chosen so there would be little mass on zero variance as there is some evidence that this may be leading to the model selecting regimes of unreasonably short duration. The priors can be viewed as being reasonably agnostic but capturing some reasonable beliefs, such as that vast changes in relationship between productivity and the independent variables is unlikely. By considering a couple of priors I am able to get a sense about the robustness of the results to the prior.

13. Some of my early analysis for Model 2 looked at the effect on long term productivity growth but many of the calculations were sensitive as often the sum of the coefficients on the lagged dependent variables were around one.

14. In similar models which allow either a structural change from 1990-4 or two structural changes – one in 1990 and another in 1995, there is generally stronger evidence of a 1990-4 structural change (rather than a 1995 change). This makes the previous results somewhat less convincing. However another interpretation is that Greenspan identified a structural break that occurred before 1995 and so this comparison period captures some of the productivity increase.

It should be noted that the data does not provide compelling evidence of a structural break. For example for the Baseline Model with prior 1 the median of the dummy coefficient is virtually zero for both the sample using data to Dec Q 1996 and data to Dec Q 1999. Even with the whole sample, though the median is above 0.25, the distribution is highly dispersed (again see Figure 5). So though there is more evidence of a productivity increase using this Bayesian method, the posterior distribution of the parameter is highly dispersed, so a productivity decrease or no change in productivity are also reasonably likely. Nevertheless the conclusions in the main text, that there was a reasonable probability of a productivity growth increase and the evidence for a productivity increased over time, both hold.

15. The reduction in volatility of the control variables due to the Great Moderation may mean that there is no reduction in the volatility in the error term during the sample despite a decrease in the variance of productivity growth. Note also that unlike Kim and Nelson, only one structural change is allowed.

16. For both priors, the initial regime’s variance is distributed Inverted Gamma 2(5,5) and the ratio of the two regimes’ variances are distributed Inverted Gamma 2(5,5). It is also is assumed that there is no regime shift in the regression coefficients in the first three years of the sample. Without this assumption there are some signs of non-convergence, with some evidence of a structural break very early in the sample. Greenspan may have been likely to discount such evidence of a break.

17. From an econometric perspective this result could be an artifact of the model trying to minimize the errors from each regime.

18. The Markov switching results provide some evidence of a moderation of productivity volatility, though the results differ in the extent to which they suggest it is from a reduction of volatility in the 1970s, or more recently, depending on the prior. Generally
the reduction in volatility is earlier than what many authors would have in mind when they refer to “the Great Moderation”.

I also experimented with a model that allowed two regimes for the variance and two regimes for the coefficients. The results suggest an economically significant productivity increase in the second half of the 1990s (consistent with the results in the main text). The model also estimated a small dummy coefficient shift toward the end of the sample and slight changes in variance towards the end of the sample. It did not detect the structural change in the variance suggested in the Markov switching model discussed in the main text.

19. Potential drawbacks of this approach are that the movements in the estimated intercept term could just reflect serial correlation in the errors and this model does not allow for heteroscedasticity. For more details on the Kalman filter and its estimation see Hamilton (1994). Time varying parameter techniques have been used to examine changes in productivity in previous work by Roberts (2001).

20. The mean square error of the filter is around 0.09 for the whole sample for the Baseline Model also indicating there is a fair degree of uncertainty about the filter and suggesting that a decision maker should give reasonable weight to a variety of productivity growth scenarios.

21. The analysis in this paper does not consider the effect of this (or other) data that may have influenced Greenspan’s view about the likelihood of a productivity increase.

References


Figure 2: Andrews’ Test Statistic for Structural Break with Unknown Break Point (70 percent of sample)
Table 1. Prior Probability of at Least a 0.25 Percentage Point Increase in Growth

<table>
<thead>
<tr>
<th>Prior</th>
<th>Baseline Model</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.32</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Based on 2000 draws from distribution. Reported for case where all parameters are allowed to change at break (values are similar where only the constant parameter is allowed to shift). Reports mass of dummy constant coefficient.
Figures 3: Priors

Priors for coefficients based on Baseline Model allowing all parameters to change. Generated from 2000 draws and smoothed with a kernel.
Figure 4: Posterior Probability that Quarterly Productivity Rose by More than 0.25 Percentage Points in 1995
This figure plots the CDF for the dummy coefficient for the Baseline Model with prior 1 where only the constant term is allowed to change at 1995. The figure indicates, for example, that for the whole sample the 30th percentile is around -2.
Table 2: Evidence of Structural Change Using Markov Switch Model for Baseline Model

<table>
<thead>
<tr>
<th></th>
<th>Mean of Dummy</th>
<th>Probability that Dummy Greater than 0.25 (0.10)</th>
<th>Variance Regime 1</th>
<th>Variance Regime 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior A</td>
<td>0.58</td>
<td>0.94 (0.97)</td>
<td>0.47</td>
<td>0.18</td>
</tr>
<tr>
<td>Prior B</td>
<td>0.53</td>
<td>0.92 (0.98)</td>
<td>0.45</td>
<td>0.18</td>
</tr>
<tr>
<td>Prior A Using Data to Q4 1995</td>
<td>0.21</td>
<td>0.48 (0.66)</td>
<td>0.52</td>
<td>0.22</td>
</tr>
<tr>
<td>Prior A Using Data to Q4 1997</td>
<td>0.06</td>
<td>0.44 (0.50)</td>
<td>0.52</td>
<td>0.21</td>
</tr>
<tr>
<td>Prior A Using Data to Q4 1999</td>
<td>0.10</td>
<td>0.43 (0.51)</td>
<td>0.51</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Based on 50000 iterations (after a burn-in of 2000 iterations that are discarded).
Figure 6a: Probability of Structural Change in Coefficients

Figure 6b: Probability of Structural Change in Variance
Figure 7: CDF for Dummy Coefficient (Prior A)
Figure 8: Kalman Filter Estimate of Intercept Using Whole Sample

- Model 1 (less controls)
- Model 2 (more controls)
- Baseline Model