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THE EFFECT OF UNCERTAINTY ON MONETARY POLICY: HOW GOOD ARE THE BRAKES?

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Resumen

En la práctica los cambios de política monetaria tienden a producir una trayectoria de tasas de interés poco volátil, mientras que las trayectorias de tasas de interes de política derivadas de modelos teóricos son mucho más variables. Este trabajo investiga si la incorporación de incertidumbre puede reconciliar la teoría con la práctica. Se observa el parámetro de incertidumbre no genera más suavización cuando sus efectos son directamente incorporados en el modelo. Por otro lado, incertidumbre sobre la sensibilidad del producto a la tasa de interés puede aumentar la suavización de la política óptima, pero la trayectoria de tasa de interés es todavía considerablemente más variable que la observada en la práctica.

Abstract

In practice, monetary policy changes tend to produce a smooth path for interest rates while the path of policy interest rates generated by models is often considerably more variable. This paper investigates whether the inclusion of uncertainty can help reconcile the theory to the practice. It shows that parameter uncertainty does not induce much smoothness when its effects are directly incorporated into a model. Uncertainty about the interest sensitivity of output can increase the smoothness of optimal policy in a model, but the path of policy interest rates generated is still considerably more variable than that observed in practice.

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1 Introduction

In most industrial countries, official interest rate changes tend to be 'smooth'. That is, rates are adjusted relatively infrequently and in small steps. In contrast, the path of interest rates that emerges as optimal from macroeconomic models is, in general, considerably more volatile. This is also the case for the paths of interest rates that are implied by simple Taylor-type rules, unless a sufficiently large weight is put on an interest-rate 'smoothing' term that penalises large movements in the policy interest rate. Do these contrasting outcomes imply that policy-makers are adopting sub-optimal monetary policy strategies, or are there factors which are not captured in the models which justify the strategies that are pursued in practice?

One possible explanation for the divergence between the models and observed practice is that the former fail to adequately capture the uncertainty that impinges on the monetary policy decision.[1] Most notably, Brainard (1967) highlighted the fact that uncertainty about model parameters can induce less 'aggressive' actions on the part of the policy-maker, than those which result when uncertainty is ignored. Consequently, this paper investigates the extent to which different forms of uncertainty affect the optimal path of interest rates. It does so by incorporating uncertainty in a simple model of the Australian economy, and examining the impact of various forms of uncertainty on the volatility of the instrument of monetary policy.

This paper complements the analysis of Rudebusch (1999) who conducts a similar analysis for the US economy. One difference between his analysis and that in this paper, is the inclusion of another transmission channel of monetary policy, namely monetary-policy-induced changes in the exchange rate on output and inflation. It also extends Shuetrim and Thompson's (1999) analysis of uncertainty in the Australian context.

Before investigating smoothness in Australia, in Section 2, the practice of interest-rate smoothing by industrial-country central banks is documented, and some possible explanations that have been advanced for this behaviour are reviewed. Section 3 focuses explicitly on uncertainty as an explanation for smoothing and summarises the growing literature that examines the impact of various types of uncertainty on the monetary policy process. Section 4 describes briefly the simple model of the Australian economy and the methodology that will be used to examine the effect of uncertainty. Section 5 presents the empirical results, and Section 6 concludes.

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[1] Of course, another explanation is that monetary policy has, to date, been conducted suboptimally.

The main findings of the paper are that the introduction of uncertainty does not necessarily explain the divergence between model-derived optimal policy and observed outcomes. Rather, different types of uncertainty have differing effects on the degree of smoothness in the path of official interests implied by the model of the Australian economy used here. General parameter uncertainty does not have much impact on smoothness. Shuetrim and Thompson (1999) find that the incidence and persistence of the uncertainty determines whether it results in more or less smoothness. Soderstrom (1999) obtains similar results to those in this paper in an analytical model. These findings, however, are in contrast to recent results for the US (Sack 1998) or the UK (Martin and Salmon 1999), and some possible explanations for the difference are discussed below.

However, uncertainty about the average interest sensitivity of the economy – that is, how good the policy brakes are – is shown to have a significant impact on the degree of smoothness. Increasing the mean interest sensitivity of the economy by one standard deviation results in a much larger degree of smoothness but one that is still smaller than that observed in practice.

2 Facts and Theories of Smoothing

2.1 Facts

The path of short-term interest rates that results from the monetary policy decisions of most industrial-country central banks tends to be smooth. Table 1 documents the fact that central banks tend to change their policy settings relatively infrequently and in small steps.[2] The table also shows that subsequent policy moves in the same direction are more common than policy reversals, and that there tends to be relatively long periods of inaction prior to a reversal.[3] The smooth path of official interest rates that underpins Table 1 is illustrated in Graph 1.

The central banks of Germany/EMU and Canada appear to move interest rates more frequently than the others in the sample. However, more recently, both those central banks have tended to adjust rates less frequently. In the past three years, policy rates have only been adjusted thirteen times in Canada and four times in Germany/EMU.

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[2] Note that the table refers to nominal, rather than real rates. While the former are generally the policy instrument of central banks, the latter are often the instrument of monetary policy in empirical models including the one used in this paper. If inflation and inflation expectations are relatively persistent, this distinction will not greatly affect the comparison of theory and practice.

[3] Rudebusch (1995) documents the pattern of changes in the Fed funds rate in the United States in more detail and estimates hazard functions for continuations and reversals.

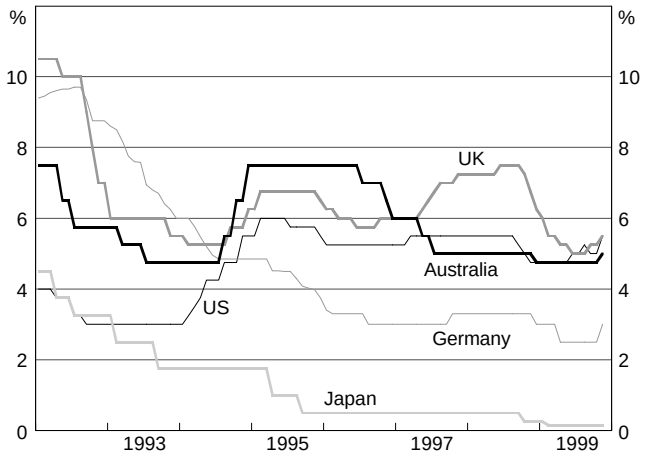
Table 1: Policy Adjustments
(January 1992 – November 1999[a])

Country	Number of changes		Average number of days between changes			Average size of change Basis points		
	Continuations	Reversals	All	Continuations	Reversals	All	Continuations	Reversals
Australia	12	3	195	134	438	63	67	50
US	15	5	144	68	374	33	35	25
UK	25	5	99	84	179	42	44	30
Germany/EMU[b]	80	10	32	20	123	10	9	20
Japan	8	0	326	326	n.a.	54	54	n.a.
Sweden	49	5	47	32	195	27	27	28
Canada	33	5	51	40	123	34	35	25

a Except Sweden (since December 1992) and Canada (since July 1994)
b EMU after January 1999

Australia: cash rate
US: Federal funds rate
UK: repo rate
Germany/EMU: repo rate
Japan: call rate
Sweden: discount rate
Canada: overnight rate

Graph 1: Official Interest Rates



In considering whether these paths of policy interest rates are smooth, it is necessary to consider what the appropriate benchmark is. In the literature to date, two benchmarks have been proposed. Firstly, the observed pattern of official interest rates has been compared to the optimal policy path derived from a macroeconomic model of the economy, where the policy-maker has the standard objective function which does not include an interest-rate smoothing term.

This benchmark may be misleading because it ignores the effect of other information available to the policy-maker that is not captured in the model. For example, the model captures the average performance of the economy in history,

whereas at any point in time, the policy-maker may consider that it has some knowledge about the residuals of the equations in the model, particularly with regard to future exogenous shocks (elections, for example). Even so, this does not explain the relative frequency of continuations and reversals; that is, the high degree of autocorrelation of official interest rates.

A second benchmark that is used is the path of interest rates derived from a policy rule, generally a Taylor-type rule. In small closed-economy macro models (such as that in Svensson (1997)), the Taylor rule and optimal policy are nearly equivalent, because all the state variables are in the rule. However, in larger models, the Taylor rule provides only an approximation to the path of interest rates derived from optimising the model. Certainty equivalence does not apply once uncertainty is introduced (Orphanides 1998). Thus a Taylor-rule that is close to optimal in a deterministic world is not necessarily so in a stochastic one.

To reconcile the differences between the degree of interest-rate smoothing in theory and practice, one approach that has been commonly adopted is to simply impose interest-rate smoothing on the model. This can be done by including a lagged interest rate term in a Taylor-type rule or by including the variance of interest rate changes in the policy-maker's objective function. While such modifications reduce the volatility of interest rates, they do not explain the observed serial correlation. These modifications are also somewhat unsatisfactory as they are somewhat ad hoc (although Woodford (1999) derives a rationale for interest-rate smoothing from first principles). Consequently in this paper, we try to identify more explicitly the factors that might induce less aggressive policy changes in practice, focussing primarily on uncertainty.

2.2 Theories

Eijffinger, Schalling and Verhagen (1999) break down the above pattern of behaviour into two facets. Firstly, they describe as interest-rate 'stepping' the fact that policy rates are adjusted in discrete steps rather than continuously, despite new policy-relevant information arriving almost constantly.[4] Secondly, they describe smoothing as the process whereby policy is adjusted only gradually towards the desired position. For much of this paper, the term interest-rate smoothing will be used to include both forms of behaviour.

[4] Conventionally, the decision-making bodies of most central banks meet at most once a month, thereby providing a bound on the frequency of policy changes. Multiple inter-meeting policy changes are extremely rare.

Lowe and Ellis (1997) discuss three possible explanations for this pattern of interest-rate smoothing.[5] Firstly, smooth changes in policy interest rates may have the maximum effect on long-term interest rates. This argument was made by Goodfriend (1991) and is developed more theoretically by Woodford (1999). Goodfriend argues that the central bank is able to communicate its intentions more clearly to participants in the market by generating a smooth path of short-term interest rates, thereby allowing participants to infer future policy actions and build them into the long rates. The forward-looking behaviour of the market participants effectively undoes the smoothing behaviour of the policy-maker (Goodhart 1999). This suggests that a model which directly incorporates long-term interest rates and accurately reflects the expectations formation of market participants may generate a smoother path for policy interest rates.

Similarly, the relative infrequency of policy changes may increase the impact of the policy announcements when they actually occur. Lowe and Ellis (1997) provide some support for this hypothesis by finding that the effect of policy announcements on consumer sentiment in Australia is non-linear. That is, the announcement of the policy change itself has an effect on consumer sentiment, irrespective of the size of the change. They also find some evidence that the shift to explicit policy announcements in Australia in the early 1990s was associated with a larger impact on consumer sentiment than previously.

The second explanation for smoothing that Lowe and Ellis consider is that policy-makers may dislike frequent reversals in the path of official interest rates because such behaviour might undermine public confidence in the monetary authorities and create instability in financial markets (Goodfriend 1987 and Cukierman 1996). For example, Goodhart (1999) cites a description of the Bank of England's recent behaviour (itself, far from the near random walk implied by economic models) as "almost laughable … like a drunk staggering from side to side down the street". Furthermore, the criticism(?) that the Monetary Policy Committee's actions were "fickle", and "influenced by the latest anecdotal or statistical evidence, swaying its opinions one way or the other and back again", would be an accurate description of the policy outcomes if the Monetary Policy Committee were to follow the dictates of an optimising macro model.

This rationale for smoothing is difficult to test because there have been few instances where central banks have pursued a policy which has resulted in volatile

[5] There are other strands of literature that consider smoothing in terms of the seasonal movements in interest rates (Mankiw and Miron 1991), and in terms of the optimal inflation tax (Mankiw 1987 and Barro 1989) which will not be discussed here.

rates.[6] Nevertheless, to investigate this hypothesis, Lowe and Ellis (1997) examine whether long-term bond yields are more volatile around periods when there are policy reversals. They find that there is some evidence of increased volatility in Australia, the UK and the US, but that it is generally short-lived. However, if central banks were to move to a regime where reversals were more commonplace, volatility may decline. This would particularly be the case if financial market participants had a good understanding of the central bank's reaction function.

The third explanation is that the nature of the monetary-policy decision process requires that the central bank build a consensus before a change in interest rates can be adopted (Goodhart 1996). As the evidence to defend a particular action may often only accumulate slowly, so the consensus-building process may also be drawn out. This may be particularly the case where the monetary policy decision is taken by a committee rather than by a single policy-maker (Blinder 1995b).

More formally, this infrequency of policy changes can also be motivated by Dixit-Pindyck uncertainty considerations. If there are costs in implementing policy changes, then in an uncertain world, there is an option value to waiting and not reacting to each piece of economic information as it comes to hand (Eijffinger, Schalling and Verhagen 1999).

Nevertheless, if the policy-maker(s) were to take the evidence of the economic model at face value, that should provide sufficient evidence to justify a policy decision. The fact that this doesn't occur suggests that the economic models are lacking some critical ingredients. In the next section, we discuss the ingredient of uncertainty.

3 Uncertainty and Smoothing

The long-standing explanation for the observed smoothness of official interest rates is that policy decisions are made under uncertainty. Until recently this had rarely been taken into account explicitly in policy models, as additive (mean-zero) shocks were generally the only form of uncertainty considered. As most models assumed a quadratic objective function for policy (most commonly, squared deviations of inflation from target and output from potential), the economy was linear and its structure known to the policy-maker, then certainty equivalence

[6] The disinflation in the United States in the early 1980s is one such period, although the instrument of monetary policy at the time was non-borrowed reserves rather than a short-term interest rate. Interestingly, Mayer (1999) cites fears of generating instability in financial markets as a possible explanation for 'excessive' smoothing by the Fed in the 1970s.

implied that the policy-maker's uncertainty about the future shocks would not affect the policy decision.

More recently, Brainard's (1967) discussion of uncertainty has been seriously re-considered. Brainard noted that while certainty equivalence implies that additive uncertainty provides no justification for smooth adjustment of policy, multiplicative uncertainty can. In this section, we discuss four different forms of multiplicative uncertainty – parameter uncertainty, model uncertainty, mean-parameter uncertainty and data uncertainty – and their impact on policy outcomes. There is not much difference between the first three forms of uncertainty but the small distinction is useful for expository purposes.

3.1 Parameter uncertainty

In his analysis, Brainard focused explicitly on uncertainty about the parameters in the model that describes the economy. In particular, there may be uncertainty about the impact of interest changes on output and inflation. In this environment, the policy-maker has to trade-off the desire to return these variables to their target values as quickly as possible, with the desire to minimise the risk of increased volatility in output and inflation that arise because policy changes might have a larger impact than expected. As a consequence, in the one-period model that Brainard uses, the policy-maker moves interest rates by less to return inflation and output to target than if there were no uncertainty.

The presence of parameter uncertainty does not necessarily imply that the policy-maker should be less aggressive (ie, produce a path of official rates that is smoother), particularly when there is uncertainty about more than one parameter. Whether or not it does, is essentially an empirical question. Using a model of the Australian economy, Shuetrim and Thompson (1999) find that uncertainty about the economy's dynamics can increase the activism of policy, depending on the location of the uncertainty. In the US context, Weiland (1998) also argues that uncertainty-induced caution does not allow the policy-maker the benefit of experimentation to better learn the true structure of the economy. In a non-linear world, however, such experimentation may be particularly costly.

In contrast, Sack (1998) finds that the introduction of parameter uncertainty to a VAR model of the US economy reconciles much of the difference between the observed path of the Fed funds rate and that implied by a VAR model without such uncertainty. Martin and Salmon (1999) replicates these results for the UK. In each case, however, as the aim of the exercise was to reconcile the estimated path of official interest rates and the path that actually occurred, while parameter uncertainty was taken into account, only the observed path of additive shocks was considered.

3.2 Model uncertainty

More fundamentally, the policy-maker may be uncertain about the model that best describes the economy. One could regard this as encompassing parameter uncertainty. The omitted variables in the model should have insignificant coefficients. A general form of model uncertainty would then consider the possibility that these parameters were in fact significant.

Blinder (1995a) provides a simple solution to this dilemma: 'use a wide variety of models and don't ever trust any one of them too much.' Sargent (1998) and Onatski and Stock (1999) address this proposal more technically and find that such uncertainty generally results in a more aggressive approach as the policy-maker seeks to avoid "worst-case" outcomes.

Both of these latter analyses address the issue of 'robust' control across a range of possible models of the economy rather than 'optimal' control within one particular model. Sargent describes the policy-maker's decision process in such a world as 'planning against [the worst, thereby] assuring acceptable performance under a range of specification errors' (p. 5). That is, the policy-maker practises disaster avoidance. Whether this cautious approach implies more or less aggressive policy actions, Sargent argues, depends on the nature of the disasters to be avoided. Of relevance to the results obtained below, Onatski and Stock find that the possibility that monetary policy might have almost no effect prompts a more aggressive response.

A similar consideration of robust control in the context of monetary policy rules has long been advocated by McCallum.[7] He argues that the robustness of a monetary policy rule across different economic models is a crucial characteristic in determining a rule that the central bank should follow. However, robustness of this sort has generally been examined in an environment of additive uncertainty, but the parameter uncertainty within each model has not been taken account of (see, most notably, the volume edited by Bryant, Hooper and Mann (1993)).

3.3 Mean-parameter uncertainty

A variant on the two previous forms of uncertainty is mean-parameter uncertainty (Rudebusch 1999). Here, the focus is on the significant parameters within a particular model. Parameter uncertainty implies that, for example, the effect of interest rates on activity is (normally) distributed about a given mean. Thus there is only a small possibility that interest rates will have an impact that is surprisingly large. In practice, however, the policy-maker may believe that the average impact

[7] See particularly, McCallum (1988).

of interest changes is considerably larger than that implied by the model, perhaps because the model is mis-specified.

In a deterministic world, the higher mean effect of policy implies that policy will be less aggressive than that implied by the (mis-specified) model. If there is also parameter uncertainty, the result is not so clear cut. This is most easily seen in the following variant of the Svensson (1997) model discussed by Batini, Martin and Salmon (1999):

$$y_t = -bi_{t-1} + e_t \quad \text{and} \quad p_t = ap_{t-1} + y_{t-1},$$

where y is output, i, the policy interest rate and π is inflation.

If inflation is the sole objective for monetary policy, the optimal interest rate is given by

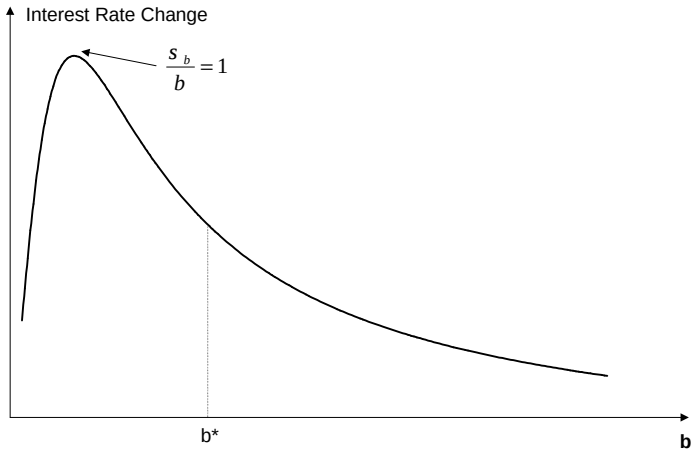
$$i_t = \frac{\bar{a}\bar{b}}{\bar{b}^2 + s_b^2} p_t$$

where $\bar{a}$ and $\bar{b}$ are the means of the parameters in the two equations, and s_b^2 is the variance of b.

In this model, whether an increase in average interest sensitivity (an increase in $\bar{b}$) increases or decreases the aggressiveness of monetary policy depends on whether the coefficient of variation $s_b / \bar{b}$ (the inverse of the t-statistic) is greater than or less than one. If the interest rate term is significant (b^* in Graph 2), the coefficient of variation is less than one, and hence an increase in interest sensitivity (an increase in b) decreases the aggressiveness of monetary policy.

Conversely, if we decrease the interest sensitivity parameter (while maintaining the same degree of uncertainty about it), initially this will increase the aggressiveness of monetary policy. However, once the mean of the parameter is less than one standard deviation from zero, further declines in it will actually decrease policy aggressiveness. This is because the costs of 'perverse' outcomes, whereby an increase in interest rates leads to an increase in inflation, is large enough to offset the benefits of the 'normal' case of an increase in interest rates leading to a decrease in inflation. These arguments are illustrated in Graph 2 which plots the interest rate change against the mean value of the interest-rate sensitivity parameter, b.

Graph 2: Mean parameter uncertainty and interest rate changes



In a number of countries, the estimated effect of changes in official rates on output and inflation might be regarded as small, particularly given the media exposure that surrounds each small change in interest rates. This suggests that the general public and financial markets, as well as policy-makers may believe that the effect is indeed larger than empirically estimated.

Table 2: Effect of a 50 Basis Point Loosening in the Policy Interest Rate
(percentage points, relative to baseline)

After:	4 Quarters	8 Quarters
Australia		
GDP Growth	0.26	0.35
Inflation	0.18	0.33
US		
GDP Growth	0.3	0.55
Inflation	0.1	0.3
UK		
GDP Growth	0.23	0.53
Inflation	0.13	0.51

Source: US: Reifschneider et al (1999)
UK: Bank of England (1999)
Australia: derived from the model described in Lowe and Ellis (1997)

Table 2 summarises the effect of a sustained 50 basis point change in policy rates as estimated in representative macroeconomic models in the US, the UK and Australia. The individual impact of any one change is not particularly large, although as discussed in Section 2 above, if the public or financial markets saw such a change as the first of a sequence of changes in the same direction, their perception of the effect of the change may incorporate the expected impact of the future changes too.

The existing empirical work has generally not addressed the issue of mean parameter uncertainty. Rudebusch (1999) finds that mean uncertainty about the interest rate sensitivity of output or about the persistence of inflation has some impact on the aggressiveness of policy, but that mean uncertainty about the slope of the Phillips curve or output persistence has little impact.

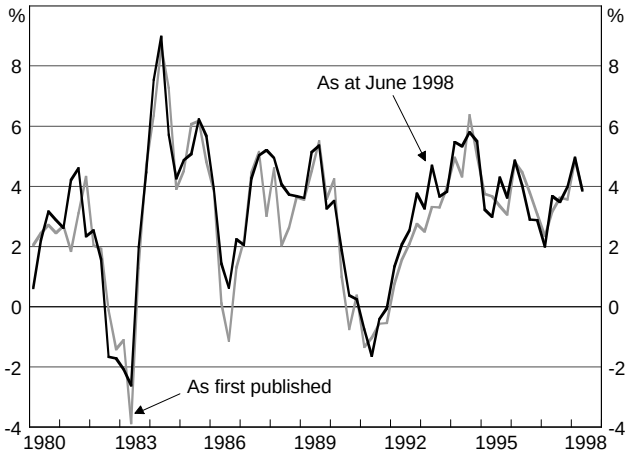
3.4 Data uncertainty

Finally, data revisions may imply that the policy-maker is uncertain about the current economic situation. In the absence of other uncertainty, data revisions are just another source of additive uncertainty, and hence certainty equivalence implies that they should have no impact on the policy decision. Thus, the inclusion of data uncertainty will not affect the optimal policy benchmark. However, if Taylor rules are used as the benchmark for policy, data revisions will play a role, because certainty equivalence no longer applies (Orphanides 1998).

In Australia, as in most countries, one important source of data uncertainty is revisions to GDP. Graph 3 shows the divergence between the first published estimate of four-quarter-ended GDP growth and the current estimate.[8] If one were to compare the first published estimate of the level of GDP with the most recent estimate, the divergence would be even greater, as, in Australia, revisions to GDP are, on average, upwards.

[8] This draws on work by Lyndon Moore.

Graph 3: GDP revisions
Four-quarter ended growth



For the policy-maker and for policy models that incorporate a Phillips-curve type supply-side, this poses particular problems for the estimate of the output gap. Estimating potential output is problematic even absent revisions to the estimate of actual GDP. Orphanides (1998) shows that introducing real-time output gap uncertainty into a model of US monetary policy, results in a policy that is considerably less aggressive than that implied by a policy rule that ignores such considerations. Rudebusch (1999) finds that data uncertainty reduces the aggressiveness of policy to deviations of inflation and output from target in a Taylor rule. More fundamentally, Isard, Laxton and Eliasson (1999) consider the performance of various monetary policy rules in a non-linear model of the US economy with uncertainty about the output gap and find that Taylor-type rules are generally not robust.

4 Model and Methodology

To investigate the impact of the various forms of uncertainty described in Section 3, we use as our benchmark the path of interest rates that results from the optimisation of a small macroeconomic model of the Australian economy.[9] The model is a slightly simpler version of the model used in Lowe and Ellis (1997), although the impact of interest rate changes on output and inflation are comparable.

The objective function for monetary policy is the standard weighted average of squared deviations of inflation from target, and output from potential. In adopting this as the objective function, we are assuming that the paths of official interest

[9] A full description of the model is provided in Appendix A.

rates described in Section 2 were set by policy-makers with such an objective function in mind.

The transmission of monetary policy occurs through two channels: directly through the impact of short-term interest rates on output,[10] and indirectly through the impact of exchange rate changes on output and on imported goods prices.

In the model, short-term interest rates affect output with a two-quarter lag. In more fully specified models of Australian GDP, the lag tends to be between two and six quarters (Gruen, Romalis and Chandra 1997). The output gap, in turn, affects inflation directly one quarter later, and indirectly through its impact on unit labour costs in a wage Phillips curve. The effect of the output gap on unit labour costs is larger than that directly on inflation, so that the effect of the output gap on unit labour costs is the main channel through which monetary policy can have permanent effects on the inflation rate.

The exchange rate responds to changes in interest rates with a lag of one quarter. This then causes a contemporaneous movement in imported goods prices which feeds into inflation a further quarter later. Imported goods prices account for around 40 per cent of the consumer price basket. A 10 per cent depreciation of the exchange rate leads to about a one percentage point increase in the year-ended inflation rate after one year.

To introduce multiplicative and additive uncertainty into the model, we need distributions for the parameters in the model and the shocks to each equation, respectively. The parameter distributions were formed from the variance-covariance matrix for each equation.[11] The distribution of the shocks for each equation were derived from the residuals obtained from estimating each equation over the sample period 1985-1998, allowing for covariance in the residuals across equations.

The optimal policy response could, in theory, be calculated at this stage. However, as this was not analytically tractable, we derived numerical solutions. To examine the effect of parameter uncertainty, a set of 50 parameter draws was taken from a normal distribution for each of the parameters of interest.[12] Then the

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[10] Empirical work has generally been unable to uncover any significant link between long-term interest rates and activity in Australia. Hence, the rationale for smoothing discussed by Goodfriend (1991) and Woodford (1999) is not captured in this model.

[11] We did not allow for covariance across equations in the parameter distributions, so the system variance-covariance matrix of the parameters is block-diagonal.

[12] We do not allow for learning by the policy maker about the parameters of the model.

economy was subjected to an additive shock in each equation, every period for a total of 50 periods. Using the approach outlined in Shuetrim and Thompson (1999), the optimal stance of policy was calculated every period under the assumption that there were no future shocks.[13] This procedure was then repeated for another 49 sets of additive shocks, thereby generating 50 simulated paths for the official interest rate, each 50 periods long.

To summarise the smoothness of official interest rates, we are interested in the average absolute change in short-term interest rates in each path. The variability of interest rates is measured by the standard deviation of the absolute change in the short-term official interest rate. The distribution of this statistic is not normal, hence we report the median absolute change in the interest rates, in addition to the average change.

5 Results

The benchmark for interest rate variability we use is that which results from the inclusion only of additive uncertainty in the model. As can be seen in Table 3, under additive uncertainty, the path of official interest rates generated by the model is extremely volatile compared to that observed in practice. The average change in official interest rates is also considerably greater than that observed in practice. Official interest rates were changed by an average of 8 percentage points each quarter, and the standard deviation of these changes was around 5.6 percentage points.[14] Graph 4 shows the distribution of the average absolute interest rate change that resulted from each of the 50 draws, and illustrates the positive skew in the distribution.

[13] The zero-bound on nominal interest rates was not enforced during the simulations. Orphanides and Wieland (1998) investigate the implications of such a constraint.

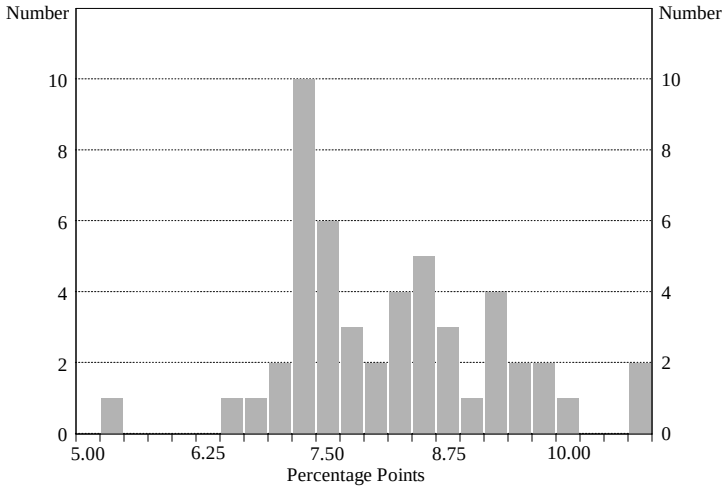
[14] Arguably, other parameters in the model might change quite significantly if such a volatile pattern of interest rate changes was the norm.

Table 3: The Effect of Additive Uncertainty on Interest Rate Volatility
(All figures are in percentage points)

	Observed volatility[a]		Model with additive uncertainty only
	Real	Nominal	
Absolute change in official interest rates |Δr| – Mean	0.85	0.87	8.0
– Median	0.57	0.71	6.8
Std dev |Δr| – Mean	0.9	0.9	5.8
– Median	0.9	0.9	5.6

a: Over the period 1985-1999

Graph 4: Frequency distribution of average interest rate changes



Here, as in all the other simulations that are discussed in this section, the paths of official interest rates that are generated exhibit minimal (if any) serial correlation, in contrast to that observed in practice. That is, none of the forms of uncertainty discussed here are able to explain the relative frequency of continuations and reversals in policy changes.

5.1 Parameter Uncertainty

Table 4 summarises the results when uncertainty about the parameters is incorporated in the model. At this stage, there is no mean uncertainty: the policy-maker assumes that the mean of each parameter is as estimated in the model. We did not allow for uncertainty about every parameter in the model, but rather focussed on the 10 main parameters of the model in the output, inflation, unit

labour cost, import price and real exchange rate equations.

Table 4: Parameter Uncertainty
(percentage points)

Form of uncertainty	Additive only	Full parameter	Interest-rate sensitivity of output	Phillips curve term in wage equation	Relative importance of domestic and imported inflation	Adjustment of output to potential in output equation
$\|\Delta r\|$ – Mean	8.0	8.4	7.7	8.0	8.0	8.1
– Median	6.8	7.1	6.5	6.8	6.8	6.8
Std dev $\|\Delta r\|$ – Mean	5.8	6.1	5.6	5.8	5.8	5.8
– Median	5.6	6.1	5.5	5.6	5.6	5.7

The table shows that the introduction of "full" parameter uncertainty does not greatly affect the variability in policy interest rates compared with that when only additive uncertainty is considered, and in fact, marginally increases it. Uncertainty about the sensitivity of output to interest rate changes seems to decrease interest rate variability only slightly.

These results are in contrast to those in Sack (1998) and Martin and Salmon (1999), where parameter uncertainty increased the smoothness of policy substantially. One possible explanation for the different findings is that, as Shuetrim and Thompson (1999) demonstrate empirically and Soderstrom (1999a) demonstrates analytically, whether parameter uncertainty increases smoothness depends on the nature of the uncertainty and its interaction with the lag structure of the economy. Secondly, Sack and Martin and Salmon use the actual path of shocks (according to their models) which affected the US and UK economies to derive their results, whereas here we use multiple paths.

Consequently, we conducted a similar exercise to Sack and Martin and Salmon by simulating the model with the observed residuals over the sample period, and then introducing the various forms of uncertainty. Table 5 summarises the results from this exercise.

Table 5: Parameter Uncertainty with Historical Shocks
(percentage points)

Form of uncertainty	Additive only	Full parameter	Interest-rate sensitivity
$\|\Delta r\|$ – Mean	4.3	4.8	4.3
– Median	3.9	4.0	4.1
Std dev $\|\Delta r\|$ – Mean	2.8	3.0	2.9
– Median	2.8	3.0	2.9

These results show that interest rate variability is considerably reduced when only the path of historical shocks is considered. The second column of the table shows that, in this instance, full parameter uncertainty increases interest rate volatility, but if there is only uncertainty about the sensitivity of output to the interest rate, then interest rate volatility is approximately unchanged.

The interest rate variability is lower with the historical shocks than most of the draws shown in Graph 4 because the actual path of the shocks matters. The historical shocks are not completely random, unlike those that underpin Graph 4. The draws in our simulations are taken from a normal distribution with no serial correlation. The historical shocks have no significant serial correlation and are not significantly different from a normal distribution (in most cases), but have sufficient non-normality and serial correlation to generate the results in Table 5.

To further narrow down the interaction of the additive and parameter uncertainty, we ran a set of simulations where there was uncertainty only about the interest sensitivity parameter and the shock in the output equation (the results are not shown here). In this instance, interest rate variability was reduced when there was uncertainty about the interest-rate parameter, a result similar to that found by Rudebusch (1999). This again, highlights that it the exact nature of the uncertainty affects the conclusions that can be drawn about the implications of uncertainty for interest rate volatility.

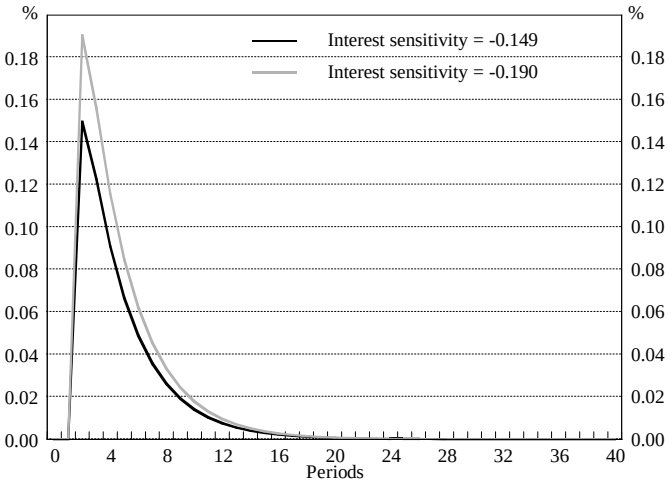
5.2 Mean parameter uncertainty

The above results assume that the policy-maker believes that the mean effect of interest changes on output (say) is the same as that implied by the model estimated with the historical data. Next we allow the parameters in the economy to have different means from those in the estimated model and also allow the policy-maker to realise this fact, while still maintaining the same degree of uncertainty (that is,

the variance of the parameter is not affected by a shift in its mean).

We focus particularly on the effect of interest rate changes on output. Firstly, we increase the impact of interest changes on output by one standard deviation. That is, interest rate changes are now more powerful, and the policy-maker is aware of that fact. Graph 5 shows the impulse response of output to a one percentage point change in official rates under the estimated and the new parameter value, –0.15 and –0.19 respectively.

Graph 5: Impulse response of output with differing interest sensitivity



As noted in Section 3, whether increases in mean interest rate sensitivity increase policy smoothness depends on the coefficient of variation. Here, as the interest rate term is significant, one would expect that an increase in interest rate sensitivity would increase smoothness. The third and fourth columns of Table 6 suggests that this is certainly the case.

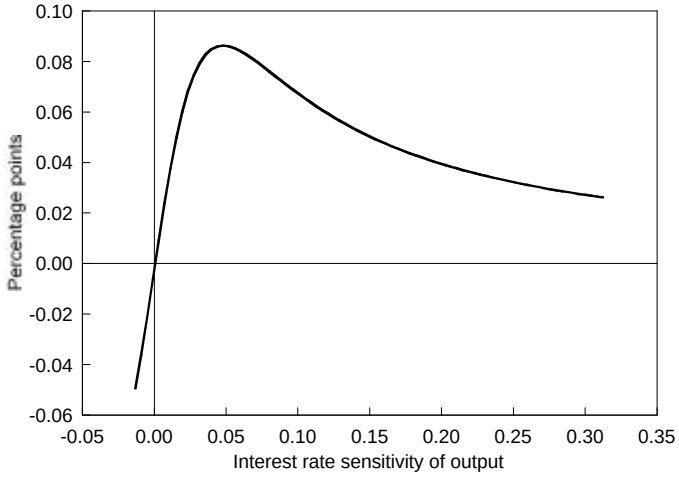
Table 6: Mean Parameter Uncertainty
(percentage points)

Form of uncertainty	Additive only	Interest rate sensitivity parameter	Mean interest-rate sensitivity – one std dev larger	Mean interest-rate sensitivity – two std dev larger	Mean interest-rate sensitivity – two std dev smaller
$\|\Delta r\|$ – Mean	8.0	7.6	6.0	5.0	14.4
– Median	6.8	6.5	5.1	4.2	12.2
Std dev $\|\Delta r\|$ – Mean	5.8	5.6	4.6	3.6	10.4
– Median	5.6	5.5	4.3	3.6	10.4

Interest rate volatility is reduced by around 25 per cent with a one standard deviation increase in interest sensitivity. A two standard deviation increase in interest sensitivity decreases interest rate volatility even further. If on the other hand, interest rate sensitivity is *reduced* by two standard deviations, interest rate volatility is substantially increased. This is because, in this instance, the economy is extremely insensitive to interest rate changes (the coefficient is close to zero).

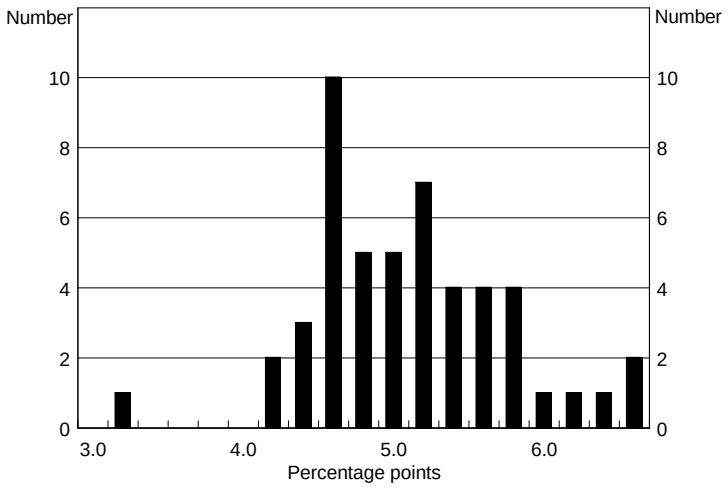
These results illustrate the analysis in Section 3.3 above. As further evidence of this, Graph 6 traces out the optimal interest rate response to a temporary one percent increase in output as the interest rate parameter is varied, that is, as the interest rate sensitivity of the economy is changed. The graph traces out a curve similar to that obtained analytically above in Graph 2.

Graph 6: Interest rate response to an output shock, with varying interest-rate sensitivity



Graph 7 shows the frequency distribution of the average absolute change in official interest rates in each path. It shows the lower interest-rate volatility in each of the paths, compared to that illustrated in Graph 4.

Graph 7: Frequency distribution of interest rate changes – mean parameter uncertainty



One caveat to these results is that we have confined the mean parameter uncertainty to the interest-rate sensitivity of output. A shift in the mean of this parameter may be associated with changes in other equations in the model, thereby offsetting the impact on interest-rate volatility. However, re-estimating the output equation while imposing the higher interest rate coefficient did not affect the other coefficients significantly, but rather only resulted in larger residuals.

6 Conclusion

Policy changes in practice tend to produce a smooth path for interest rates while the path of official interest rates generated by models or policy rules is often considerably more volatile. This paper has investigated whether the inclusion of uncertainty can help reconcile the theory to the practice. It has shown that, in general, parameter uncertainty does not induce much smoothness when its effects are directly incorporated in the model. However, particular forms of parameter uncertainty may have some impact.

The main finding of the paper is that mean parameter uncertainty about the interest sensitivity of output can reduce the aggressiveness of optimal policy in the model. Thus, if it is the case that the effectiveness of monetary policy is greater than that suggested by the estimated model *and* the policy-maker knows that, policy is likely to be less aggressive. However, the path of policy interest rates is still more volatile than that observed in practice.

An issue which this paper has not addressed is whether there are any losses from a smooth path of interest rates. Lowe and Ellis (1997) tentatively conclude that smoother policy does not generate much increase in the volatility of inflation and output. Thus, even if the policy approach that has been adopted in most

industrial countries has not been completely optimal because it has been excessively smooth, the costs of that have not been great. Moreover, there may be costs to increased volatility in interest rates which are not captured by the model, which would further reinforce that conclusion.

Finally, the results in this paper are unable to explain the relative frequency of reversals in the direction of policy as opposed to continuations that is observed in practice. The forms of uncertainty discussed in this paper are unlikely to provide an explanation. A more likely explanation might involve the potential adverse effects on the credibility of the central bank of frequent reversals in the direction of policy.

Appendix A: A Small Macroeconomic Model of Australia

The model used in this paper is a simplified version of the model used by Lowe and Ellis (1997). The motivation for each equation is provided there, along with additional references. The specification of each equation of the model with diagnostics are given below. All variables except for the interest rate are expressed in log levels; interest rates are expressed in annualised terms. Each equation is estimated from 1985:Q1 to 1998:Q4. In our simulations, the constants in each equation were calibrated so that the model possessed certain steady state properties. All numbers expressed in parentheses are standard errors.

Endogenous Variables

Output

$$\Delta y_t = \underset{}{\alpha_1} - \underset{(0.085)}{0.244}\left(y_{t-1} - y^*_{t-1}\right) + \underset{(0.120)}{0.064}\,\Delta y_{t-1} - \underset{(0.041)}{0.149}\,r_{t-2}$$

$\bar{R}^2 = 0.255$ Standard Error = 0.007
Jarque-Bera test: 1.97 [p=0.37] LM(4) Test: 1.09 [p=0.37]
Durbin-Watson = 2.09

where y is real non-farm output, y^* is potential output, and r is the real cash rate.

Prices

$$\Delta p_t = \underset{}{\alpha_2} - \underset{(0.010)}{0.088}\,p_{t-1} + \underset{(0.013)}{0.068}\,ulc_{t-1} + \underset{(0.004)}{0.020}\,pm_{t-1} + \underset{(0.021)}{0.107}\left(y_{t-1} - y^*_{t-1}\right)$$

$\bar{R}^2 = 0.864$ Standard Error = 0.002
Jarque-Bera test: 1.12 [p=0.57] LM(4) Test: 0.93 [p=0.45]
Durbin-Watson = 1.68

where p is the level of the underlying CPI, *ulc* is a measure of unit labour costs, and *pm* is import prices. Prices are modelled as a markup on unit labour costs and imported goods prices. The restriction that the sum of coefficients on prices, unit labour costs and import prices sum to zero was imposed.

Unit Labour Costs

$$\Delta ulc_t = \underset{(0.475)}{0.848}\,\Delta p_{t-1} + \underset{(0.475)}{0.152}\,\Delta p_{t-2} + \underset{(0.078)}{0.303}\left(y_{t-1} - y^*_{t-1}\right) + \underset{(0.197)}{0.135}\,\Delta\left(y - y^*\right)_{t-4}$$

$\bar{R}^2 = 0.221$ Standard Error = 0.010
Jarque-Bera test: 0.368 [p=0.83] LM(4) Test: 0.57 [p=0.68]

Durbin-Watson = 2.32

The unit labour cost equation is a linear Phillips Curve incorporating adaptive expectations. The assumption of adaptive expectations has historically provided the best fit for Australian data. The equation was estimated with the restriction that the coefficients on lagged inflation sum to one. This restriction is not rejected by the data. The final term in the equation captures 'speed-limit' effects. That is, the speed with which the output gap is closed also affects wage pressures in addition to the size of the gap itself.

Import Prices

$$\Delta pm_t = \alpha_3 - \underset{(0.079)}{0.137}\left(pm_{t-1} + e_{t-1}\right) - \underset{(0.045)}{0.601}\Delta e_t$$

$\bar{R}^2 = 0.798$ Standard Error = 0.015
Jarque-Bera test: 2.22 [p=0.33] LM(4) Test: 0.42 [p=0.79]
Durbin-Watson = 1.75

where *e* is the nominal exchange rate. We assume unitary pass through of movements in the exchange rate in the long-run and that world prices are zero.

Real Exchange Rate

$$\Delta rer_t = \alpha_4 - \underset{(0.108)}{0.331}\left(rer_{t-1} - tot_{t-1}\right) + \underset{(0.195)}{0.377}\, r_{t-1} + \underset{(0.121)}{0.749}\,\Delta cpsdr_t$$

$\bar{R}^2 = 0.537$ Standard Error = 0.031
Jarque-Bera test: 1.64 [p=0.44] LM(4) Test: 1.25 [p=0.30]
Durbin-Watson = 1.78

where *rer* is the real exchange rate, measured using the real trade weighted index, *tot* is the terms of trade and *cpsdr* is the commodity price index measured in SDR's.

Exogenous Variables

Potential Output

$$y_t^* = \alpha_5 + \underset{(0.051)}{0.115}\, tot_t^* - \underset{(0.035)}{0.075}\, rer_t^* + \underset{(0.014)}{1.361}\, y_t^{US}$$

where tot^* is the steady state level of the terms of trade, rer^* is the steady state level of the real exchange rate and y^{US} is the level of US real output.

For other exogenous variables, we assume:

Terms of Trade

$\Delta tot_t = 0$

Commodity Prices

$\Delta \text{cpsdr}_t = 0$

US Real Output

$\Delta y_t^{US} = 0.00625$

Identities and definitions

Nominal Exchange Rate

Assuming foreign inflation is zero:

$\Delta \text{e}_t = \Delta \text{rer}_t - \Delta \text{p}_t$

Real Cash Rate

$r_t = i_t - \Delta_4 p_t$

where $\Delta_4 p_t = p_t - p_{t-4}$.

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