The Effect of Uncertainty on Monetary Policy: How Good are the Brakes?

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In most industrial countries, official interest rate changes tend to be "smooth." That is, rates are adjusted relatively infrequently and in small steps. Yet the path of interest rates that emerges as optimal from macroeconomic models is, in general, considerably more volatile. So are the paths of interest rates implied by simple Taylor-type rules, unless a sufficiently large weight is put on an interest rate smoothing term that penalizes large movements in the policy interest rate. Do these contrasting outcomes imply that policymakers in industrial countries are adopting suboptimal monetary policy strategies, or are there factors not captured in the models that justify the strategies 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. Most notably, Brainard (1967) highlighted the fact that uncertainty about model parameters can induce less aggressive actions on the part of the policymaker than those that result when uncertainty is ignored. This paper investigates the extent to which different forms of

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uncertainty affect the optimal path of interest rates. It does so by incorporating uncertainty into a simple model of the Australian economy and examining the impact of various forms of uncertainty on the volatility of the monetary policy instrument.

This paper complements that of Rudebusch (1999), who conducts a similar analysis for the U.S. economy. One difference between his analysis and ours is the inclusion of another transmission channel of monetary policy, namely, the effect of 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 the smoothness of monetary policy changes in Australia, we document, in section 1, the practice of interest rate smoothing by industrial-country central banks, and we review some possible explanations that have been advanced for this behavior. Section 2 focuses explicitly on uncertainty as an explanation for smoothing and summarizes the growing literature that examines the impact of various types of uncertainty on the monetary policy process. Section 3 describes briefly a simple model of the Australian economy and the methodology that will be used to examine the effect of uncertainty. Section 4 presents the empirical results, and section 5 concludes.

The main finding of the paper is 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 smoothness of the path of official interest rates 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 determine whether it results in more or less smoothness. Soderstrom (1999), using an analytical model, obtains results similar to those in this paper. These findings, however, are in contrast to recent results for the United States (Sack, 1998) and the United Kingdom (Martin and Salmon, 1999), and some possible explanations for the difference are discussed.

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

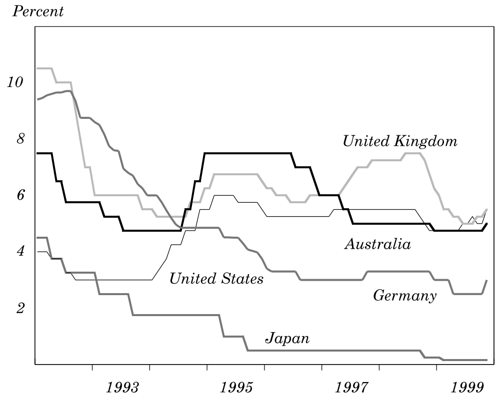
1. Facts and Theories of Smoothing

1.1 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.[1] The table also shows that a series of policy moves in the same direction is more common than a policy reversal and that a relatively long period of inaction tends to precede a reversal.[2] The smooth path of official interest rates that underpins table 1 is illustrated in figure 1.

The central banks of Germany (and later the European Central Bank under European Monetary Union) and Canada appear to move interest rates more frequently than the others in the sample.

Figure 1. Official Interest Rates in Selected Industrial Countries



Source: Reserve Bank of Australia.

1. The table refers to nominal rather than real rates. Although 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.

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

Table 1. Policy Adjustments in Selected Industrial Countries, January 1992-November 1999[a]

		Number of changes		*Average number of days between changes*			*Average size of change (basis points)*		
Country	*Interest rate*	*Continuations*[b]	*Reversals*	*All*	*Continuations*	*Reversals*	*All*	*Continuations*	*Reversals*
Australia	Cash rate	12	3	195	134	438	63	67	50
United States	Federal funds rate	15	5	144	68	374	33	35	25
United Kingdom	Repo rate	25	5	99	84	179	42	44	30
Germany[c]	Repo rate	80	10	32	20	123	10	9	20
Japan	Call	8	0	326	326	NA	54	54	NA
Sweden	Discount	49	5	47	32	195	27	27	28
Canada	Overnight	33	5	51	40	123	34	35	25

Source: Authors' calculations.
NA, not applicable.
a. Data for Sweden begin in December 1992 and those for Canada in July 1994.
b. A continuation is a change in interest rates in the same direction as the previous change.
c. Data are for countries participating in European Monetary Union after January 1999.

Recently, however, both those central banks have tended to adjust rates less frequently. In the three years ending in November 1999, policy rates were adjusted only thirteen times in Canada and four times in Germany and the euro area.

In identifying whether these paths of policy interest rates are smooth, it is necessary to determine what the appropriate benchmark is. In the literature to date, two such benchmarks have been proposed. One is to compare the observed pattern of official interest rates with the optimal policy path derived from a macroeconomic model of the economy, where the policymaker has the standard objective function, which does not include an interest rate smoothing term. This benchmark may be misleading, however, because it ignores the effect of information available to the policymaker that is not captured in the model. For example, the model captures the average performance of the economy over time, whereas at any point in time the policymaker may consider that he or she 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 used is the path of interest rates derived from a policy rule, generally a Taylor-type rule. In macroeconomic models of small, closed economies (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 optimizing 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.

One commonly adopted approach used to reconcile the differences between the degrees of interest rate smoothing in theory and in practice 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 policymaker's objective function. Although such modifications reduce the volatility of interest rates, they do not explain the observed serial correlation. These modifications are also somewhat unsatisfactory in that 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, focusing primarily on uncertainty.

1.2 Theories

Eijffinger, Schalling, and Verhagen (1999) break down the above pattern of behavior into two facets. First, they describe as interest rate "stepping" the adjustment of policy rates in discrete steps rather than continuously, despite new, policy-relevant information arriving almost constantly.[3] Second, they describe smoothing as the process whereby policy is adjusted only gradually toward the desired position. For much of this paper, the term "interest rate smoothing" will be used to include both forms of behavior.

Lowe and Ellis (1997) discuss three possible explanations for this pattern of interest rate smoothing.[4] First, 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 long-term rates. The forward-looking behavior of market participants effectively undoes the policymaker's smoothing behavior (Goodhart, 1999). This suggests that a model that directly incorporates long-term interest rates and accurately reflects the formation of market participants' expectations may generate a smoother path for policy interest rates.

Similarly, the relative infrequency of policy changes may increase the impact of policy announcements when they do 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 nonlinear. That is, the announcement of the policy change itself has an effect on consumer sentiment, irrespective of the size of

3. Conventionally, the decisionmaking bodies of most central banks meet at most once a month, thereby providing a bound on the frequency of policy changes. Multiple intermeeting policy changes are extremely rare.

4. Other strands of literature 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.

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 policymakers may dislike frequent reversals in the path of official interest rates because such behavior 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 recent behavior of the Bank of England's Monetary Policy Committee (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 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 committee were to follow the dictates of an optimizing macroeconomic model.

This rationale for smoothing is difficult to test because few instances are recorded of central banks pursuing a policy that resulted in volatile rates.[5] 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 United Kingdom, and the United States, but that it is generally short-lived. However, if central banks were to move to a regime where reversals were more commonplace, volatility might 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, the consensus building process might likewise be drawn out. This may particularly be the case where the monetary policy decision is made by a committee rather than by a single policymaker (Blinder, 1995b).

5. The disinflation in the United States in the early 1980s is one such period, although the instrument of monetary policy at the time was nonborrowed 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 Federal Reserve in the 1970s.

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 policymakers took the evidence of the economic model at face value, that evidence should be sufficient to justify a policy decision. The fact that this does not occur suggests that the economic models are lacking some critical ingredients. In the next section we discuss the ingredient of uncertainty.

2. 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 factor was rarely taken explicitly into account in policy models, because additive (mean-zero) shocks were generally the only form of uncertainty considered. Because most models assumed a quadratic objective function for policy (most commonly, squared deviations of inflation from target and of output from potential) and that the economy is linear and its structure known to the policymaker, certainty equivalence implied that the policymaker's uncertainty about future shocks would not affect the policy decision.

More recently, however, Brainard's (1967) discussion of uncertainty has been seriously reconsidered. Brainard noted that although 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 among the first three forms of uncertainty, but the small distinction is useful for expository purposes.

2.1 Parameter Uncertainty

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 rate changes on output and inflation. In this environment the policymaker has to trade off, on the one hand, the desire to return these variables to their target values as quickly as possible, and on the other, the desire to minimize the risk of increased volatility in output and inflation that arises because policy changes might have a larger impact than expected. As a consequence, in the one-period model that Brainard uses, the policymaker moves interest rates by less to return inflation and output to their targets than if there were no uncertainty.

The presence of parameter uncertainty does not necessarily imply that the policymaker should be less aggressive (that is, produce a smoother path of official rates), 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 U.S. context, Weiland (1998) also argues that uncertainty-induced caution does not allow the policymaker the benefit of experimentation to better learn the true structure of the economy. In a nonlinear world, such experimentation may be particularly costly.

In contrast, Sack (1998) finds that introducing parameter uncertainty into a vector autoregressive (VAR) model of the U.S. economy reconciles much of the difference between the observed path of the federal funds rate and that implied by a VAR model without such uncertainty. Martin and Salmon (1999) replicate these results for the United Kingdom. In each case, however, as the aim of the exercise was to reconcile the estimated path of official interest rates with the path that actually occurred, although parameter uncertainty was taken into account, only the observed path of additive shocks was considered.

2.2 Model Uncertainty

More fundamentally, the policymaker 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 are 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 policymaker seeks to avoid worst-case outcomes.

Both the 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 policymaker's decision process in such a world as "planning against [the worst, thereby] assuring acceptable performance under a range of specification errors" (1998, p. 5). That is, the policymaker practices 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 (1999) 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 (see especially McCallum, 1988). He argues that the robustness of a monetary policy rule across different economic models is a crucial characteristic in determining the rule that the central bank should follow. However, robustness of this sort has generally been examined in an environment of additive uncertainty; the parameter uncertainty within each model has not been taken into account (see, most notably, the volume edited by Bryant, Hooper, and Mann, 1993).

2.3 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 economic 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 policymaker may believe that the average impact of interest changes is considerably larger than that implied by the model, perhaps because the model is misspecified.

In a deterministic world, the higher mean effect of policy implies that policy will be less aggressive than that implied by the (misspecified) 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):

$$y_t = -\,\mathrm{E}i_{t-1} + \varepsilon_t \ ,$$

$$\pi_t = \mathrm{D}\pi_{t-1} + y_{t-1} \ ,$$

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

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

$$i_t = \frac{\bar{\mathrm{a}}\bar{\mathrm{b}}}{\bar{\mathrm{b}}^2 + \sigma_b^2}\,\pi_t \ ,$$

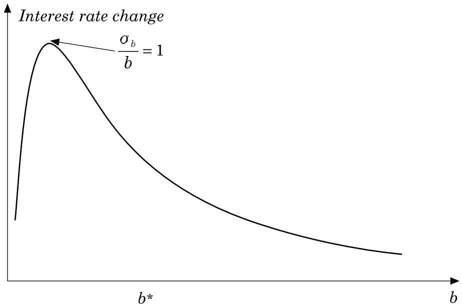
where $\bar{\mathrm{a}}$ and $\bar{\mathrm{b}}$ are the means of the parameters in the two equations, and σ_b^2 is the variance of b.

In this model, whether an increase in average interest rate sensitivity (an increase in $\bar{\mathrm{E}}$) increases or decreases the aggressiveness of monetary policy depends on whether the coefficient of variation $\sigma_b/\bar{\mathrm{b}}$ (the inverse of the t-statistic) is greater than or less than one. If the interest rate term is significant (b^* in figure 2), the coefficient of variation is less than 1, and hence an increase in interest rate sensitivity (an increase in b) decreases the aggressiveness of monetary policy.

Conversely, if we decrease the interest rate 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 comes about because the costs of "perverse" outcomes, whereby an increase in interest rates leads to an increase in inflation, are 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 figure 2, which plots the interest rate change against the mean value of the interest rate sensitivity parameter b.

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

Figure 2. Mean Parameter Uncertainty and Interest Rate Changes



markets, as well as policymakers, may believe that the effect is indeed larger than empirically estimated.

Table 2 summarizes the effect of a sustained 50-basis-point change in policy rates as estimated in representative macroeconomic models of the United States, the United Kingdom, and Australia. The individual impact of any one change is not particularly large. However, as discussed in section 1, if the public or financial markets see 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 as well.

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.

2.4 Data Uncertainty

Finally, data revisions may imply that the policymaker 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

Table 2. Effect of a Sustained 50-Basis-Point Reduction in the Policy Interest Rate in Australia, the United States, and the United Kingdom (percentage points, relative to baseline)

Country	*After four quarters*	*After eight quarters*
Australia		
Effect on GDP growth	0.26	0.35
Effect on inflation	0.18	0.33
United States		
Effect on GDP growth	0.30	0.55
Effect on inflation	0.10	0.30
United Kingdom		
Effect on GDP growth	0.23	0.53
Effect on inflation	0.13	0.51

Source: For the United States, Reifschneider, Tetlow, and Williams (1999); for the United Kingdom, Bank of England (1999); for Australia, derived from the model described in Lowe and Ellis (1997).

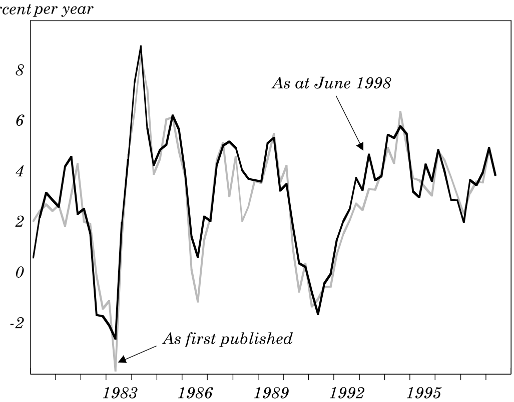
will play a role, because certainty equivalence no longer applies (Orphanides, 1998).

In Australia, as in most countries, one important source of data uncertainty is revisions to GDP. Figure 3 shows the divergence between the first published estimate of GDP growth over the preceding four quarters and the current estimate for the same period.[6] 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, because in Australia revisions to GDP are, on average, upward.

For the policymaker 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 in the absence of revisions to the estimate of actual GDP. Orphanides (1998) shows that introducing real-time output gap uncertainty into a model of U.S. 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 toward 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 nonlinear model of the U.S. economy with uncertainty about the output gap and find that Taylor-type rules are generally not robust.

6. This draws on work by Lyndon Moore, Reserve Bank of Australia.

Figure 3. Initial and Revised Estimates of GDP Growth in Australia[a]



Source: Reserve Bank of Australia.
a. Estimates are for the four quarters preceding the initial estimate.

3. Model and Methodology

To investigate the impact of the various forms of uncertainty just described, we use as our benchmark the path of interest rates that results from the optimization of a small macroeconomic model of the Australian economy. (See the appendix for a full description of the model.) The model is a slightly simpler version of that used in Lowe and Ellis (1997), although the impacts 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 the target, and of output from potential. In adopting this as the objective function, we assume that the paths of official interest rates described in section 1 were set by policymakers 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,[7] and indirectly through the impact of exchange rate changes on

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

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, 1999). The output gap, in turn, affects inflation directly one quarter later, and indirectly through its impact on unit labor costs in a wage Phillips curve. The effect of the output gap on unit labor costs is larger than that directly on inflation, so that the effect of the output gap on unit labor 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 percent of the consumer price basket. A 10 percent depreciation of the domestic currency leads to about a 1-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.[8] The distribution of the shocks for each equation was derived from the residuals obtained from estimating each equation over the sample period 1985-98, 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 fifty parameter draws was taken from a normal distribution for each of the parameters of interest.[9] Then the economy was subjected to an additive shock in each equation, every period for a total of fifty periods. Using the approach outlined in Shuetrim and Thompson (1999), we calculated the optimal stance of policy every period under the assumption that there were no future shocks.[10] This

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

9. We do not allow for learning by the policymaker about the parameters of the model.

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

procedure was then repeated for another forty-nine sets of additive shocks, thereby generating fifty simulated paths for the official interest rate, each fifty periods long.

To summarize 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.

4. Results

The benchmark for interest rate variability we use is that which results from the inclusion in the model of additive uncertainty only. As can be seen in table 3, under additive uncertainty, the path of official interest rates generated by the model is extremely volatile compared with that observed in practice. The average change in official interest rates is also considerably greater than 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.[11] Figure 4 shows the distribution of the average absolute interest rate change that resulted from each of the fifty draws and illustrates the positive skew in the distribution. Here, as in all the other simulations discussed in this section, the paths of official interest rates that are generated exhibit minimal (if any) serial correlation, in contrast to what is 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.

4.1 Parameter Uncertainty

Table 4 summarizes the results of analyses in which uncertainty about the parameters is incorporated into the model. At this stage there is no mean uncertainty: the policymaker assumes that the mean

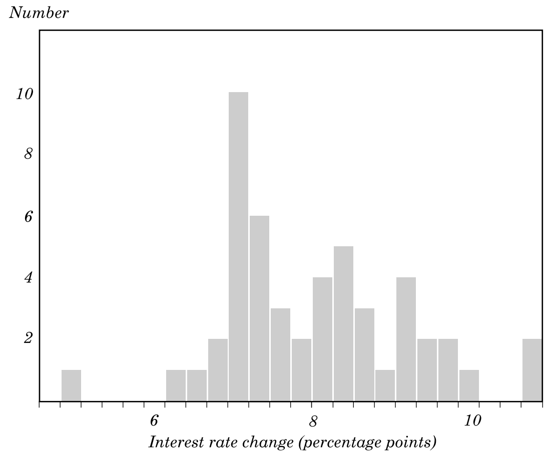
11. Arguably, other parameters in the model might change quite significantly if such a volatile pattern of interest rate changes were the norm.

Table 3. Effect of Additive Uncertainty on Interest Rate Variability (percentage points)

	Observed volatility[a]		*Model with additive uncertainty only*
	Real	*Nominal*	
Absolute change in official interest rates $\|\Delta r\|$			
Mean	0.85	0.87	8.0
Median	0.57	0.71	6.8
Standard deviation of change in official interest rates			
Mean	0.9	0.9	5.8
Median	0.9	0.9	5.6

Source: Authors' calculations.
a. Over the period 1985-99.

Figure 4. Frequency Distribution of Average Absolute Interest Rate Changes in Australia



Source: Authors' calculations.

Table 4. Effect of Parameter Uncertainty on Interest Rate Variability (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 ouput to potencial in output equation*
Absolute change in official interest rates $\|\Delta r\|$						
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
Standard deviation of change in official interest rates						
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

Source: Authors' calculations.

of each parameter is as estimated in the model. We did not allow for uncertainty about every parameter in the model, but rather focused on the ten main parameters of the model in the output, inflation, unit labor cost, import price, and real exchange rate equations. 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; in fact, that variability marginally increases. 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 difference in findings is that, as Shuetrim and Thompson (1999) demonstrate empirically and Soderstrom (1999) demonstrates analytically, whether parameter uncertainty increases smoothness depends on the nature of the uncertainty and its interaction with the lag structure of the economy. In addition, Sack and Martin and Salmon use the actual path of shocks (according to their models) that affected the U.S.

and U.K. economies to derive their results, whereas here we use multiple paths.

Consequently, we conducted an exercise similar to that of Sack and of 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 summarizes the results. 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, interest rate volatility is approximately unchanged.

Interest rate variability is lower with the historical shocks than with most of the draws shown in figure 4, because the actual path of the shocks matters. The historical shocks are not completely random, unlike those that underpin figure 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 nonnormality and serial correlation to generate the results in table 5.

To further narrow down the interaction of additive and parameter uncertainty, we performed a set of simulations in which there was uncertainty only about the interest rate sensitivity parameter

Table 5. Effect of Parameter Uncertainty with Historical Shocks on Interest Rate Variability (percentage points)

	Form of uncertainty		
	Additive only	*Full parameter*	*Interest rate sensitivity of output*
Absolute change in official interest rates $\|\Delta r\|$			
Mean	4.3	4.8	4.3
Median	3.9	4.0	4.1
Standard deviation of change in official interest rates			
Mean	2.8	3.0	2.9
Median	2.8	3.0	2.9

Source: Authors' calculations.

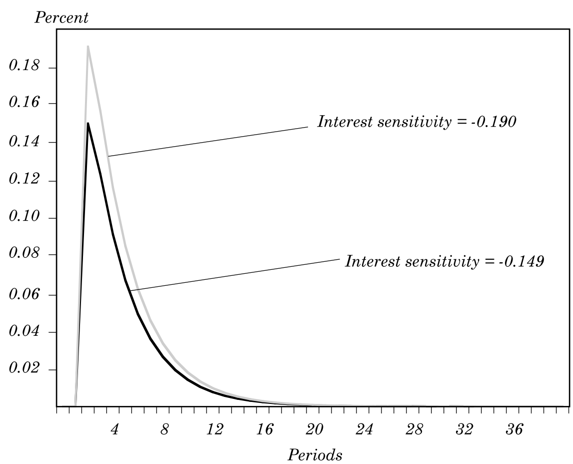
and the shock in the output equation (results not shown). In this instance, interest rate variability was reduced when there was uncertainty about the interest rate parameter, a result similar to that found by Rudebusch (1999). This again highlights that the exact nature of the uncertainty affects the conclusions that can be drawn about the implications of uncertainty for interest rate volatility.

4.2 Mean-Parameter Uncertainty

The above results assume that the policymaker believes that the mean effect of interest rate changes on, say, output 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 allow the policymaker to realize 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. First, we increase the impact of interest rate changes on output by one standard deviation. That is, interest rate changes are now more powerful, and the policymaker is aware of that fact. Figure 5 shows the impulse response of output to a 1-percentage-point change

Figure 5. Impulse Response of Output in Australia with Differing Interest Rate Sensitivities



Source: Authors' calculations.

in official rates under the estimated and the new parameter values: –0.15 and –0.19, respectively.

As noted in section 2, whether increases in mean interest rate sensitivity increase policy smoothness depends on the coefficient of variation. Here, because 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 suggest that this is certainly the case. Interest rate volatility is reduced by around 25 percent with a one-standard-deviation increase in interest rate sensitivity. A two-standard-deviation increase in interest rate 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. The reason is that, 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 2.3. As further evidence of this, figure 6 traces out the optimal interest rate response to a temporary 1 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 in figure 2.

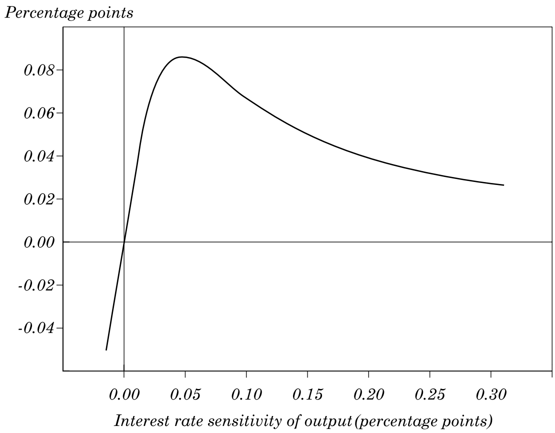
Figure 7 shows the frequency distribution of the average absolute change in official interest rates in each path. It shows the lower interest rate volatility in each of the paths compared with that illustrated in figure 4.

Table 6. Effect of Mean-Parameter Uncertainty on Interest Rate Variability (percentage points)

			Change in mean interest rate sensitivity		
	Additive only	*Interest rate sensitivity parameter*	*One standard deviation larger*	*Two standard deviations larger*	*Two standard deviations smaller*
Absolute change in official interest rates $\|\Delta r\|$					
Mean	8.0	7.6	6.0	5.0	14.4
Median	6.8	6.5	5.1	4.2	12.2
Standard deviation of change in official interest rates					
Mean	5.8	5.6	4.6	3.6	10.4
Median	5.6	5.5	4.3	3.6	10.4

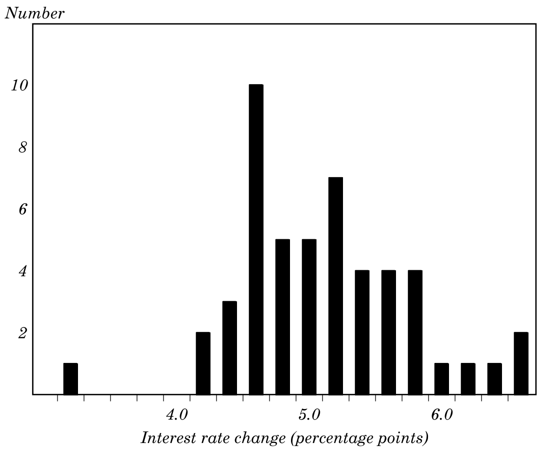
Source: Author's calculations.

Figure 6. Percentage Points Interest Rate Response to an Output Shock in Australia at Varying Interest Rate Sensitivities



Source: Authors' calculations.

Figure 7. Frequency Distribution of Interest Rate Changes in Australia under Mean-Parameter Uncertainty



Source: Authors' calculations.

One caveat to these results is that we have confined 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, reestimating the output equation while imposing the higher interest rate coefficient did not affect the other coefficients significantly, but rather only resulted in larger residuals.

5. Conclusion

Policy changes in practice tend to produce a smooth path for interest rates, whereas the optimal 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 theory with 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 rate sensitivity of output can reduce the aggressiveness of optimal policy in the model. Thus, if the effectiveness of monetary policy is greater than that suggested by the estimated model *and* the policymaker 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 not addressed here 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 of an increase in the volatility of inflation and output. Thus, even if the policy approach adopted in most industrial countries has not been optimal because it has been excessively smooth, the costs have not been great. Moreover, there may be costs to increased volatility in interest rates that the model does not capture, which would further reinforce that conclusion.

Finally, the results in this paper are unable to explain the frequency of reversals in the direction of policy, relative 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 Small Macroeconomic Model of Australia

The model used in this paper is a simplified version of that 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, is given below. All variables except for the interest rate are expressed as logarithms; interest rates are expressed in annualized terms. Each equation is estimated over the period 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 in parentheses are standard errors.

Endogenous Variables

The output equation in the model is

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

Adjusted $R^2 = 0.255$, SE = 0.007 ,
Jarque-Bera test: 1.97 (p = 0.37) , LM(4) test: 1.09 (p = 0.37) ,
DW = 2.09.

where y is real nonfarm output, y^* is potential output, and r is the real cash rate.

The price equation is

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

Adjusted $R^2 = 0.864$, SE = 0.002 ,
Jarque-Bera test: 1.12 (p = 0.57) , LM(4) test: 0.93 (p = 0.45) ,
DW = 1.68

where p is the level of the underlying consumer price index, ulc is a measure of unit labor costs, and pm is import prices. Prices are modeled as a markup on unit labor costs and imported-goods prices.

The restriction that the coefficients on prices, unit labor costs, and import prices sum to zero was imposed.

The unit labor costs equation is

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

Adjusted $R^2 = 0.221$, SE = 0.010 ,
Jarque-Bera test: 0.368 (p = 0.83) , LM(4) test: 0.57 (p = 0.68) ,
DW = 2.32.

The unit labor 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 affects wage pressures in addition to the size of the gap itself.

The import price equation is

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

Adjusted $R^2 = 0.798$, SE = 0.015 ,
Jarque-Bera test: 2.22 (p = 0.33) , LM(4) test: 0.42 (p = 0.79) ,
DW = 1.75.

where e is the nominal exchange rate. We assume unitary passthrough of movements in the exchange rate in the long run and that world inflation is zero.

The real exchange rate equation is

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

Adjusted $R^2 = 0.537$, SE = 0.031 ,
Jarque-Bera test: 1.64 (p = 0.44) , LM(4) test: 1.25 (p = 0.30) ,
DW = 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 special drawing rights.

Exogenous Variables

The equation for potential output is

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

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 U.S. real output. For other exogenous variables we assume

$$\Delta tot_t = 0 ,$$

$$\Delta cpsdr_t = 0 ,$$

$$\Delta y_t^{US} = 0.00625 .$$

Identities and Definitions

Assuming foreign inflation is zero, the nominal exchange rate is

$$\Delta e_t = \Delta rer_t - \Delta p_t .$$

The real cash interest rate is defined as

$$r_t = i_t - \Delta_4 p_t ,$$

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

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