Uncertainty about the Length of the Monetary Policy Transmission Lag: Implications for Monetary Policy

Yuong Ha
Economics Department
Reserve Bank of New Zealand

Prepared for the Sveriges Riksbank Monetary Policy Workshop, August 1999

The opinions expressed in this paper are those of the author, and do not reflect the opinions of the Reserve Bank of New Zealand. The author would like to thank Aaron Drew and Ben Hunt for helpful discussions, and Vincenzo Cassino for earlier work. All errors and omissions belong to the author.

Please address questions to: Yuong Ha, Economics Department, Reserve Bank of New Zealand – 2, The Terrace, Wellington, New Zealand – email hay@rbnz.govt.nz, Telephone: 64-4- 471 3810, Departmental fax: 64-4-473 1209

Abstract

Using stochastic simulations of the Reserve Bank of New Zealand's macroeconomic model, this paper examines the implications for monetary policy of uncertainty about the length of the monetary policy transmission lag. Uncertainty is examined from two perspectives. The first investigates the robustness of efficient inflation-forecast-based rules under transmission lag uncertainty. Robustness, in this paper, is measured by the variability of the stabilisation properties of policy rules. The results indicate that rules that are less aggressive and more forward looking are *more* robust than rules that are more aggressive and less forward looking. By using more-robust rules, policy makers are more likely to achieve outcomes that are closer to what they expect. However, while less aggressive and more forward-looking rules are more robust, the implication for monetary policy is less clear. Typically, these more-robust policy rules have higher absolute levels of inflation variability than less-robust rules. In other words, less-robust rules typically do a better job at controlling inflation regardless of the transmission lag and regardless of what the central bank believes the transmission lag to be.

The second aspect asks, if the central bank is uncertain about the length of the transmission lag, is it better to overestimate or underestimate the lag? If the central bank overestimates the lag, it believes inflation is harder to control than it really is. As a result, policy responses tend to be stronger than would be the case if the central bank knew the truth. Underestimating the lag has the opposite effect – the central bank believes inflation is easier to control and policy responds less aggressively than would be the case if the central bank knew the truth. This result suggests that it is better to overestimate the transmission lag. By behaving as if inflation is harder to control, central bank is able to counter inflationary pressures earlier and do a relatively better job at stabilising the economy.

1. Introduction

In practice, central banks form a view of how they think the economy behaves – and this view may be formalised in terms of a model – and then develop a strategy (or strategies) that will enable them to achieve their objectives. Given the range of uncertainties about how the economy behaves, achieving the policy objective may often be far more difficult than anticipated. In this paper, I focus specifically on the implications of uncertainty about the length of the transmission mechanism for the stabilisation properties of inflation-forecast-targeting strategies.

The uncertainties facing a central banker have long been recognised and the implications for monetary policy have been widely discussed in the literature. For example, in a seminal article, Brainard (1967) argued that when the policymaker is uncertain about the effect of policy actions, it may be optimal to be conservative – that is, move policy instruments by smaller magnitudes than would be the case if there was no uncertainty. Additional research, such as that by Shuetrim and Thompson (1999) and Onatski and Stock (1999) suggests, however, that the answer is not always that simple. In Shuetrim and Thompson, the authors illustrate that in a dynamic model, uncertainty about the persistence in the economy can lead to optimal policy that is more aggressive than optimal policy under certainty. Using robust control techniques, Onatski and Stock find that, in most cases, robust policies under model uncertainty are more aggressive than optimal policies under certainty.

Other aspects of model uncertainty that have been examined include: uncertainty about potential output (Drew and Hunt, 1999)[1]; policy co-ordination between two countries under model uncertainty (Frankel and Rockett, 1986; Ghosh and Masson,1988, 1991); uncertainty about whether inflation responds symmetrically or

---

[1] See, also:

Isard, P., D. Laxton and A. Eliasson (1998): "Inflation Targeting with NAIRU Uncertainty and Endogenous Policy Credibility." Paper presented at the Fourth Conference on Computational Economics, Cambridge, United Kingdom.

Smets, F. (1999): "Output gap uncertainty: Does it matter for the Taylor rule?" To appear in Benjamin Hunt and Adrian Orr (eds.) *Monetary Policy Under Uncertainty* (Wellington, New Zealand).

Wieland, V. (1998): "Monetary Policy and Uncertainty about the Natural Unemployment Rate." Paper presented at the NBER conference on Formulation of Monetary Policy.

asymmetrically to excess demand and excess supply (Laxton, Rose and Tetlow, 1993); inflation expectations and exchange rate uncertainty (Conway, Drew, Hunt, and Scott, 1998), (Cassino, Drew, and McCaw, 1999).

In addition, there is also a vast theoretical and empirical literature on the monetary policy transmission mechanism.[2] Most of this literature has examined the nature of channels through which monetary policy influences the real and nominal economy, the relative importance of these channels, and whether these channels have changed over the years.[3]

It appears that, so far, there has been relatively little work explicitly examining the implications for setting monetary policy under uncertainty about the length of the transmission lag. Blinder (1997) argues that one of the main sources of central bank error is due to failure to take proper account of the lags in monetary policy. In Haldane (1997), the author examines the implications of uncertainty about the transmission lag for the optimal inflation-targeting horizon. Using a simple macro model he showed that, relative to the actual length of the transmission lag, having too short a targeting horizon was likely to have the more damaging impact on inflation control than having an overly long targeting horizon. Intuitively, if the targeting horizon is too short, the central bank is likely to see little response in inflation following policy changes, so further policy actions are likely. However, when inflation does eventually respond, it will react by more than the central bank had originally desired. If, on the other hand, the targeting horizon is beyond the length of the transmission lag, inflation is likely to respond in the same way as it would if the central bank knew the correct transmission lag.

In this paper, I examine transmission lag uncertainty in the context of simple inflation-forecast-based rules – henceforth IFB rules.[4] This class of policy rules is currently used by the Reserve Bank of New Zealand, the Bank of Canada, and the

---

[2] For introductions to the literature, see the Symposium on the Monetary Transmission Mechanism, *Journal of Economic Perspectives*, Fall (1995) and Berk (1997).

[3] These studies have been conducted for different countries and different time periods. See, for example, Mauskopf (1990), Gruen, Romalis and Chandra (1997), Mosser (1992), Britton and Whitley (1997).

[4] This follows the convention adopted by Haldane and Batini (1998), Isard and Laxton (1999), Amano, Coletti, and Macklem (1999).

Sveridges Riksbank in their forecasting and policy models. This work is part of the Reserve Bank of New Zealand's research agenda examining the implications for monetary policy under uncertainty.[5]

Uncertainty is examined from two perspectives. The first looks at the robustness of the stabilisation properties of efficient IFB rules under transmission lag uncertainty. Robustness is measured by the variability of the stabilisation properties of policy rules. Within the class of IFB rules, the two key strategic decisions to be made are (a) at what horizon does the central bank choose to respond to deviations of inflation from target (targeting horizon) and (b) how much does the policy instrument respond to those forecasted deviations of inflation from the target rate. I examine the implications of transmission lag uncertainty on these decisions.

Using stochastic simulations, the efficient frontiers are traced out for three alternative versions of the Reserve Bank's macroeconomic model, FPS.[6] In each version, the transmission lag has been calibrated to different lengths and the efficient frontiers are derived under the assumption that the central bank knows the correct transmission lag. A sensitivity analysis is then carried out to compare the robustness of the IFB rules that lie upon these frontiers when the central bank does not know the correct transmission lag. In these uncertainty experiments, the central bank incorrectly assumes that the transmission lag is specified by one of the other two versions of the FPS model.

The results show that, of the IFB rules that lie upon the efficient frontiers, those that are relatively *less* aggressive and *more* forward looking tend to be *more* robust under transmission lag uncertainty than more aggressive and less forward-looking rules. Consistent with Haldane (1997), policymakers are more likely to get outcomes closer to what they expect by using a less aggressive and more forward-looking rule. However, the implication for monetary policy is less clear because, typically, more-robust policy rules have higher absolute levels of inflation variability than less-robust

[5] Previous Bank research on uncertainty has examined the issues of shock uncertainty (Drew and Hunt, 1998), uncertainty about the way private agents form their inflation expectations and exchange rate uncertainty (Conway, Drew, Hunt, and Scott, 1998), (Cassino, Drew, and McCaw, 1999), and potential output uncertainty (Drew and Hunt, 1999).
[6] The Reserve Bank's FPS model is discussed in Black et al (1997).

rules. In other words, it is the case that less-robust rules – rules that are more aggressive and less-forward-looking – do better at controlling inflation regardless of the actual transmission lag and regardless of what the central bank believes the transmission lag to be.

The second aspect looks at transmission lag uncertainty from an inflation forecasting perspective. In practice, a central bank is not likely to know the true length of the transmission lag. A central bank is likely to either overestimate the lag or underestimate the lag. The task of controlling the economy is likely to be more difficult as the length of the transmission lag increases. Hence, by overestimating the lag, the central bank behaves as if inflation is harder to control than it really is. Likewise, if the lag is underestimated, the central bank behaves as if inflation is easier to control than it really is. I examine which position would be better for a central bank to take from the perspective of stabilising the economy.[7] Efficient frontiers are traced out for the cases when the central bank assumes an incorrect transmission lag and then compared with the frontiers derived under certainty. The impact that each type of mistake has on the stabilisation properties of the policy rules is then examined.

The results suggest that the stabilisation properties deteriorate when the central bank underestimates the transmission lag – particularly with respect to inflation variability. Because the central bank believes inflation is easier to control, policy responses tend to be milder than would be the case if the central bank knew the truth. This results in higher inflation variability. This type of policy error has a tendency to compound over time.

However, when the central bank overestimates the transmission lag, the stabilisation properties tend to improve. Because the central bank believes inflation is harder to control, policy responses tend to counter inflationary pressures more quickly. As a result, the central bank does a relatively better job at stabilising the model economy. This may reflect that shocks to the economy tend to exhibit persistence and the error

[7] This is a similar approach to that taken by Laxton, Rose, and Tetlow (1994) where the authors examined the implications of uncertainty about whether the Phillips curve is linear or non-linear. Cassino, Drew and McCaw (1999) also use this approach to examine inflation expectations and exchange rate uncertainty.

from overestimating the transmission lag may be compensating the fact that the persistence in the stochastic shocks are typically underestimated.

The remainder of the paper is organised as follows. In section 2, there is a brief description of the Reserve Bank of New Zealand's FPS model. Section 3 describes the transmission lags in FPS and illustrates the three versions of FPS that are used in the stochastic simulation experiments. The results on the robustness of IFB rules is presented in Section 4. The implications of model misspecification are examined in Section 5. Section 6 concludes.

2. The FPS core model at a glance [8]

The core FPS model describes the interaction of five economic agents: households, firms, a foreign sector, the fiscal authority and the monetary authority. The model has a two-tiered structure. The first tier is an underlying steady-state structure that determines the long-run equilibrium to which the economy converges. The second tier is the dynamic adjustment structure that traces out how the economy converges towards that long-run equilibrium.

The long-run equilibrium is characterised by a neo-classical balanced growth path. Along that growth path, consumers maximise utility, firms maximise profits and the fiscal authority achieves exogenously-specified targets for debt and expenditures. The foreign sector trades in goods and assets with the domestic economy. Taken together, the actions of these agents determine expenditure flows that support the set of stock equilibrium conditions underlying the balanced growth path.

The dynamic adjustment process overlaid on the equilibrium structure embodies both "expectational" and "intrinsic" dynamics. Expectational dynamics arise through the interaction of exogenous disturbances, policy actions and private agents' expectations. Policy actions are introduced to re-anchor expectations when exogenous disturbances move the economy away from equilibrium. Because policy actions do not immediately re-anchor private expectations, real variables in the economy must follow disequilibrium paths until expectations return to equilibrium. To capture this notion, expectations are modelled as a linear combination of a backward-looking autoregressive process and a forward-looking model-consistent process. Intrinsic dynamics arise because adjustment is costly. The costs of adjustment are modelled using a polynomial adjustment cost framework (see Tinsley (1993)). In addition to expectational and intrinsic dynamics, the behaviour of the fiscal authority also contributes to the overall dynamic adjustment process.

On the supply side, FPS, is a single good model. That single good is differentiated in its use by a system of relative prices. Overlaid on this system of relative prices is an

[8] See Black et al (1997) for a more complete description of the FPS model. This section was taken from Drew and Hunt (1999).

inflation process. While inflation can potentially arise from many sources in the model, it is driven fundamentally by the difference between the economy's supply capacity and the demand for goods and services. Further, the relationship between goods-markets disequilibrium and inflation is asymmetric.[9] Excess demand generates more inflationary pressure than an identical amount of excess supply generates in deflationary pressure.

[9] Although the empirical evidence supporting asymmetry in the inflation process is growing, a convincing prudence argument for using asymmetric policy models is presented in Laxton, Rose and Tetlow (1994).

3. The Monetary Policy Transmission Mechanism

3.1 The FPS transmission channels

As outlined in Svensson (1997), monetary policy actions are transmitted through an open economy through several different channels. The most important are:

(1) the aggregate demand channel through interest rate changes;
(2) the inflation expectations channel; and
(3) the exchange rate channel.

In the FPS model, a monetary policy tightening through a rise in interest rates makes it more expensive to borrow and consume today relative to the future. This causes a reduction in investment and consumption, that is, a fall in aggregate demand. This fall in aggregate demand below the economy's productive capacity eventually reduces inflation. The lags in this transmission channel are due to the time it takes for aggregate demand to respond to changes in interest rates, and the time it takes for inflation to respond to the output gap.

With the inflation expectations channel, forward-looking agents perceive that tighter monetary policy will lead to lower inflation in the future. This reduces expected inflation leading to lower inflation outcomes. Again, there will be lags in the response of inflation expectations to changes in policy, and the response of inflation to changes in inflation expectations.

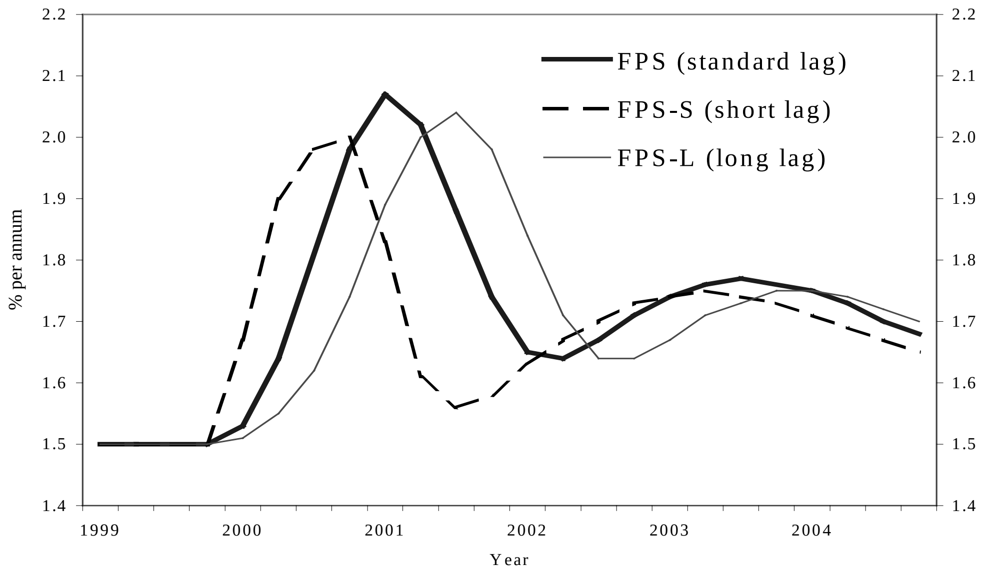
A rise in the real interest rate will lead to an appreciation of the exchange rate through the uncovered interest rate parity relationship embodied in the model. This means that imports become cheaper in New Zealand dollar terms. And since part of the basket of goods and services used in measuring CPI inflation are imports, CPI inflation will fall. There are lags in this so-called *direct* exchange rate channel due to the time it takes for import prices to respond to exchange rate movements, and the time it takes for changes in import prices to flow through into CPI inflation. In addition, there is an *indirect* exchange rate channel that has an influence on inflation. An appreciation of the exchange rate makes New Zealand goods more expensive relative to foreign goods. This reduces the demand for New Zealand exports, and shifts some domestic demand to the now-cheaper import goods. In both cases, aggregate demand for New Zealand-produced goods falls.

3.2 Illustrating the three versions of FPS, each with a different transmission lag

To examine transmission lag uncertainty, stochastic simulations are conducted on three versions of the FPS model.[10] In each version, the transmission lag has been calibrated to a different length. The first version is simply the standard FPS model (denoted FPS), where the transmission lag has been calibrated to reflect the stylised facts from data for the New Zealand economy. The second version, denoted FPS-S, has a shorter transmission lag so that inflation responds faster to policy actions. The other version, FPS-L, has a longer lag so inflation responds more slowly to policy actions.

Figure 1 illustrates the impact of a 4-quarter exchange rate shock under the three versions of the FPS model.

Figure 1: CPI inflation under different transmission lags with an exchange rate shock



[10] The technique for simulating FPS under stochastic disturbances is presented in Drew and Hunt (1998).

4. The robustness of efficient IFB rules under transmission lag uncertainty

This section traces out the efficient frontiers for each version of the FPS model under the assumption that the central bank knows the correct length of the transmission lag. Consistent with Taylor (1979), the efficient frontier is defined as the locus of the lowest achievable combinations of inflation and output variability. The policy rules that lie on each efficient frontier then become the set of benchmark policy rules that are examined when uncertainty has been incorporated.

4.1 Description of IFB rules

Under IFB rules, the policy instrument is adjusted in response to a model-consistent projection of the deviation of inflation from its target rate. This class of reaction functions can be expressed as:

$$rgap_t = rgap_t^* + \sum_{i}^{i+j} \theta_i \left(\pi_{t+i}^e - \pi^T\right),$$

where $rgap$ is the gap between the short-term nominal interest rate and the long-term nominal interest rate,[11] $rgap^*$ is its equilibrium equivalent, π_{t+i}^e is the model-consistent projection of annual CPI inflation *i* quarters ahead, and π^T is the policy target (set at 1.5 percent). The target horizon window from *i* to *i*+*j* is a calibration choice.

The standard FPS policy rule, used by the Reserve Bank in its quarterly projections, falls within this class of rules with $i = 6, j = 2$, and $\theta_i = 1.4$. That is, at time *t*, the yield gap will be raised by 1.4 percentage points (via a sufficient rise in nominal short-term interest rates) for every 1 percentage point that annual CPI inflation is projected to deviate from the target rate of 1.5 percent over the horizon of 6, 7 and 8 quarters ahead from time *t*.

[11] In the FPS model code, the policy reaction function is specified in terms of this yield spread. The policy reaction function can be rewritten to be expressed in terms of a short-term nominal interest rate.

4.2 Deriving the efficient frontier

To trace out the efficient frontiers, I use the same technique as employed by Drew and Hunt (1999), which relies on stochastic simulations of the FPS model and a grid search technique over the policy rule coefficients. To determine the set of efficient policy rules, both the magnitudes of the weights (values for θ_i) and the target horizon (values for *i*) are searched over. The targeting horizon is a three-quarter moving window starting from 1 quarter ahead and extending to 12 quarters ahead (ten different windows in all). The policy reaction weights, θ_i, range in value from 0.5 to 20. The resulting efficient frontiers for each version of the FPS model are graphed in figure 2.[12]

The root mean squared deviation (RMSD) of inflation from its target rate, and the RMSD of output (Y) from potential output are the measures of variability that have been used. The asymmetry in the response of inflation to excess demand and excess supply make this the most appropriate measure of variability to use. As a result of the asymmetric inflation process, on average, inflation is above the target rate and output is below its deterministic steady state under stochastic disturbances.[13] Relative to the standard deviation statistic, the RMSD statistic penalises policy rules that result in inflation being more above the target rate, and output being below its deterministic steady-state level.

4.3 The efficient frontiers when the central bank knows the correct transmission lag

Figure 2 plots the efficient frontiers derived under certainty for the three versions of the FPS model. The summary statistics for these frontiers are listed in appendix 1. The downward sloping nature of these frontiers suggests a trade-off between inflation

---

Rewriting the reaction function in terms of the short-term nominal interest rate gives identical model properties provided that the response coefficients, θ_i, are scaled up by roughly 30 per cent.

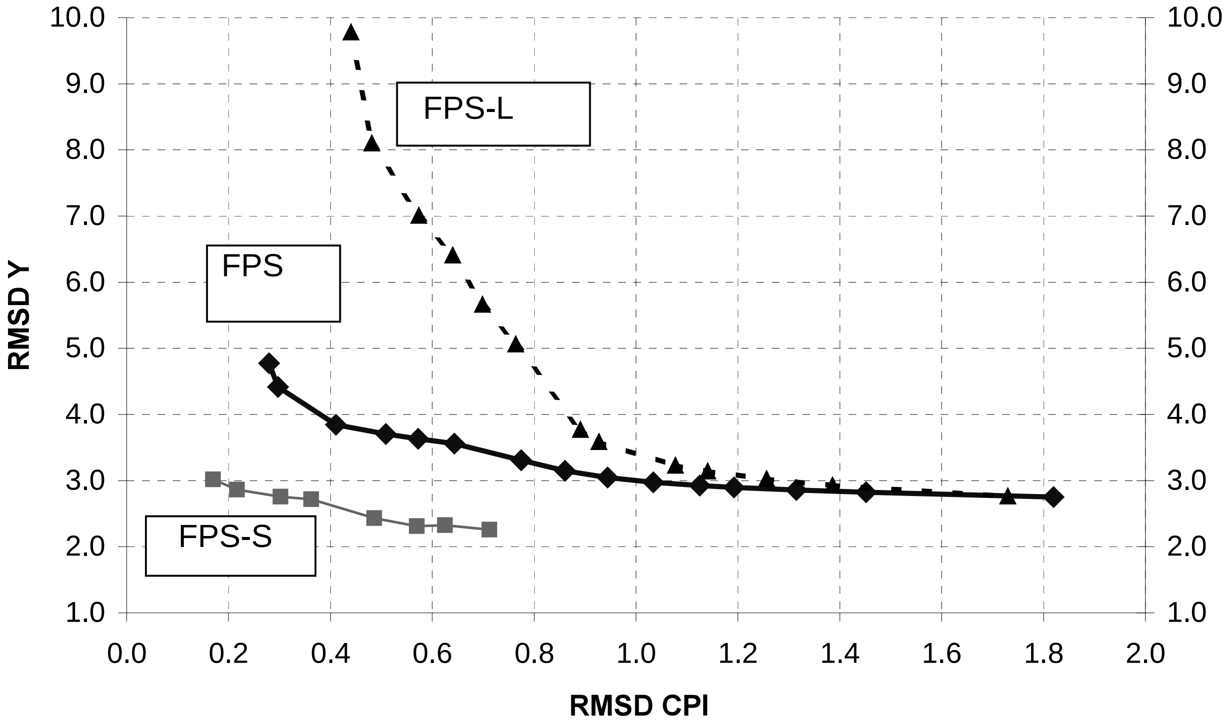
[12] The simulation statistics are calculated by averaging the results from 100 draws, where each draw has been simulated over a 25-year horizon.

[13] For a discussion of why the stochastic steady state for output is below the deterministic equilibrium, see Laxton, Rose and Tetlow (1994).

variability and output variability exists. That is, along the efficient frontier, lower inflation variability can only be achieved at the expense of higher output variability.

The best overall macroeconomic outcomes (lowest possible combinations of CPI inflation/output variability) are achieved under FPS-S, where the transmission lag is the shortest. The worse outcomes are obtained under FPS-L, where the transmission lag is the longest. This is reasonably intuitive. A central bank's job of controlling inflation is likely to be easier when the policy transmission lag is shorter.

Figure 2: Efficient frontiers for the different versions of the FPS model



4.4 Incorporating uncertainty about the transmission lag

4.4.1 Overview of the experiments

Before discussing the results, it is useful to provide a 'roadmap' of the experiments conducted in this paper. With three versions of the FPS model, there are three experiments where there is no uncertainty and these are illustrated in figure 2. These cases are denoted: FPS-S for when the true model is given by FPS-S and the central bank knows this to be the case; FPS for when the true model is given by the normal FPS model; and FPS-L for when the true model is given by FPS-L.

The results from the no-uncertainty case for each version of the FPS model then become the benchmarks to compare the results under uncertainty. For each version, there are two relevant uncertainty cases, giving a total of six uncertainty cases. Under the uncertainty experiments, the central bank sets monetary policy under an incorrect assumption of what the true model is. If the true model is given by FPS-S, the central bank may believe that the true representation of the world is given by the normal FPS model. This case is denoted S/N. Using the notation T/B, the first argument, T, represents the true model, while the second argument, B, represents the central bank's mistaken belief of the world. When the true model is FPS-S, the second uncertainty case to consider is when the central bank believes the true model to be given by FPS-L – denoted as case S/L.

Similarly, when the true model is given by the normal FPS model, the central bank can believe the true model to be given by FPS-S (case N/S) or FPS-L (case N/L)

Finally, when the true model is given by FPS-L, the central bank may believe the true model to be given by FPS-S (case L/S), or FPS (case L/N).

In terms of the stochastic simulation experiments that incorporate uncertainty, a "mistake" is made each period. The central bank sets policy each quarter on the basis of its belief about the transmission lag, and these instrument settings are then applied to the version of FPS with the correct transmission lag.[14] In the following quarter, the monetary authority sees that the inflation outcome from the previous quarter may not have been as it had expected. The simulation technique assumes that the central bank cannot determine the source of the forecast error. Hence there is no learning in this experiment – the monetary authority simply updates its starting point, persists with its belief about the transmission lag, and sets policy accordingly.

[14] This simulation technique for examining the implications of the monetary authority being uncertain about the true structure of the economy was first used in Laxton, Rose and Tetlow (1994).

4.5 Measuring the robustness of efficient IFB rules

In practice, it is highly unlikely that the central bank will know the correct length of the transmission lag. The robustness of the stabilisation properties of policy rules is an important consideration when formulating monetary policy. The question asked here is what features of IFB rules, if any, make this class of rules robust to transmission lag uncertainty?

Robustness is measured by the variability of the inflation and output stabilisation properties of policy rules. A distance index is calculated for each IFB rule on the efficient frontiers shown in figure 2. This index is defined by the following function:

$$d(x)_i = 100 * \sum_{\substack{j=1 \\ j \neq i}}^{2} \left[\alpha \left(rmsdcpi(x)_j - rmsdcpi(x)_i \right)^2 + \beta \left(rmsdy(x)_j - rmsdy(x)_i \right)^2 \right]$$

where x represents a particular rule on an efficient frontier, i represents the certainty case while j represents the uncertainty cases. The ratio α/β represents the degree to which a central bank does not like inflation variability surprises relative to output variability surprises. In this paper $\alpha = \beta = 1$, which means that the central bank does not like inflation surprises equally as much as output surprises. The results are scaled by a factor of 100. This distance index essentially calculates how far away the uncertainty outcomes are relative to the certainty outcomes. A small value for this index, d, implies that the stabilisation properties of a particular policy rule does not change much under transmission lag uncertainty. Therefore, the lower the index value, the more robust is the policy rule. The results for the efficient IFB rules once uncertainty has been incorporated are listed in tables 2, 3 and 4.

Table 1: Results for the set of efficient IFB rules under the standard FPS model

		No uncertainty – FPS		Uncertainty - N/S		Uncertainty – N/L			
θ	Horizon *I*	RMSD CPI	RMSDY	RMSD CPI	RMSDY	RMSD CPI	RMSDY	Distance index, *d*	Rank
0.5	10	1.82	2.75	1.96	2.81	1.70	2.74	**3.8**	**1**
1.0	10	1.45	2.82	1.56	2.95	1.33	2.79	**4.5**	**2**
20.0	4	0.41	3.85	0.55	4.03	0.34	3.86	**5.7**	**3**
1.4	10	1.31	2.86	1.39	3.04	1.19	2.80	**5.7**	**4**
2.0	10	1.19	2.90	1.24	3.14	1.07	2.82	**8.3**	**5**
2.5	10	1.13	2.92	1.15	3.21	1.00	2.83	**10.7**	**6**
3.5	10	1.03	2.97	1.03	3.34	0.92	2.85	**16.3**	7
5.0	10	0.94	3.04	0.91	3.51	0.85	2.88	**25.3**	**8**
10.0	4	0.51	3.70	0.72	4.23	0.41	3.75	**33.1**	**9**
7.0	10	0.86	3.15	0.82	3.72	0.82	2.93	**38.3**	**10**
5.0	4	0.64	3.56	0.90	4.17	0.51	3.65	**46.5**	**11**
10.0	10	0.77	3.31	0.74	4.04	0.82	3.11	**57.0**	**12**
7.0	4	0.57	3.63	0.83	4.37	0.45	3.70	**63.0**	**13**

Table 2: Results for the set of efficient IFB rules under the FPS-S

		No uncertainty – FPS-S		Uncertainty – S/N		Uncertainty – S/L			
θ	Horizon *i*	RMSD CPI	RMSDY	RMSD CPI	RMSDY	RMSD CPI	RMSDY	Distance index, *d*	Rank
7.0	6	0.71	2.26	0.66	2.20	0.59	2.17	**2.9**	**1**
10.0	4	0.49	2.43	0.52	2.11	0.52	2.16	**17.6**	**2**
7.0	2	0.36	2.72	0.43	2.28	0.50	2.28	**40.7**	**3**
20.0	1	0.17	3.02	0.39	2.51	0.53	2.76	**50.4**	**4**
10.0	2	0.30	2.76	0.43	2.26	0.48	2.28	**51.6**	**5**
20.0	2	0.22	2.86	0.43	2.28	0.55	2.42	**68.7**	**6**
20.0	10	0.57	2.31	0.70	1.88	1.02	1.71	**76.6**	7

Table 3: Results for the set of efficient IFB rules under the FPS-L

		No uncertainty – FPS-L		Uncertainty – L/N		Uncertainty – L/S			
θ	**Horizon** i	**RMSD CPI**	**RMSDY**	**RMSD CPI**	**RMSDY**	**RMSD CPI**	**RMSDY**	**Distance index,** d	**Rank**
0.5	10	1.73	2.76	1.84	2.73	1.98	2.76	**7.7**	**1**
1.0	10	1.39	2.93	1.51	2.91	1.63	3.02	**8.6**	**2**
1.4	10	1.26	3.02	1.39	3.01	1.50	3.20	**10.8**	**3**
2.0	10	1.14	3.14	1.28	3.13	1.38	3.45	**16.9**	**4**
2.5	10	1.08	3.23	1.22	3.22	1.31	3.65	**25.0**	**5**
5.0	6	0.76	5.06	1.04	4.53	1.33	5.47	**83.6**	**6**
10.0	4	0.57	7.00	0.89	6.58	1.42	7.47	**121.7**	**7**
7.0	6	0.70	5.66	1.00	4.96	1.10	4.88	**134.8**	**8**
5.0	10	0.93	3.58	1.06	3.61	1.15	4.73	**138.7**	**9**
20.0	4	0.48	8.10	0.85	8.12	1.18	7.16	**149.3**	**10**
7.0	4	0.64	6.41	0.92	5.89	1.59	7.54	**253.5**	**11**
7.0	10	0.89	3.77	0.99	3.95	1.11	5.85	**442.8**	**12**

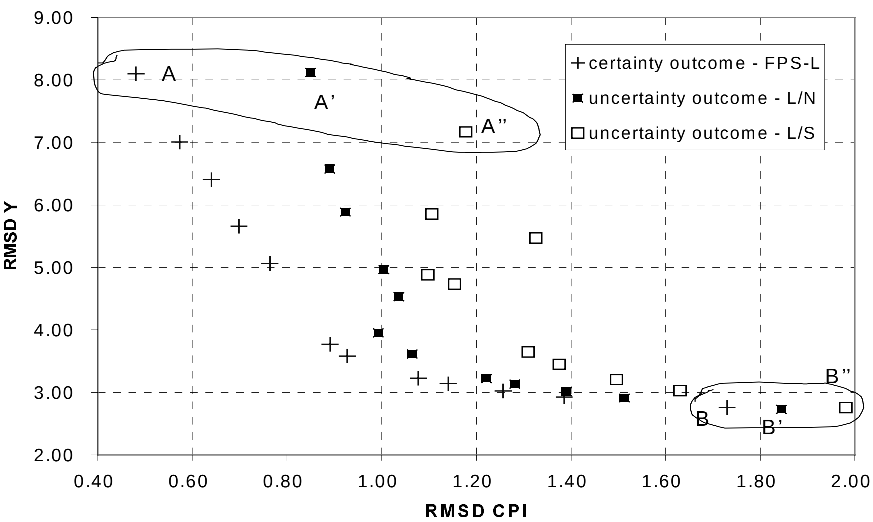
The results indicate that, of the IFB rules that lie on the computed efficient frontiers, the rules that are more robust typically have relatively low response coefficients, θ_i, and a relatively long target horizon, i - that is, rules that are less aggressive and more forward looking.[15]

These results parallel Haldane's (1997) findings. Rules that have a relatively short target horizon are more likely to have too short a horizon relative to the true transmission lag. Hence, in the process of trying to control inflation, it is not surprising to expect that these rules will yield results that may be significantly different from expectations. Being more aggressive compounds this problem.

[15] Another interesting exercise would be to calculate the robustness statistics for *inefficient* IFB rules and see if inefficient rules are more robust than efficient rules.

However, while less aggressive and more forward-looking IFB rules are more robust, more aggressive and shorter horizon rules typically achieve lower levels of inflation variability regardless of the actual transmission lag and regardless of what the central bank believes the transmission lag to be. This point can be seen in figure 3, which plots the stabilisation properties of the policy rules for the case when the actual transmission lag is specified by FPS-L. Points A, A', and A'' represent the values for the most aggressive and shortest horizon rule with $\theta_i = 20$, and a target horizon of 4, 5 and 6 quarters ahead. Points B, B' and B'' represent the values for the least aggressive ($\theta_i = 0.5$) and most forward-looking IFB rule (target horizon of 10, 11 and 12 quarters ahead). Even though the spread of B, B' and B'' is much lower under uncertainty, the absolute level of inflation variability is higher than the more aggressive and shorter horizon rule.

Figure 3: Policy rules under a long transmission lag



To put some perspective on these results, an "expected" efficient frontier has been calculated.[16] The assumption is made that each particular outcome is equally likely so in calculating the expected stabilisation properties of policy rules, each outcome has been equally weighted by a third. Figure 4 plots the expected values for three policy rules. Rule A is again the most aggressive and shortest horizon rule, rule B is the least aggressive and most forward looking, while rule C also has a long target horizon but is more aggressive ($\theta = 5$).

Figure 4: The "expected" efficient frontier for FPS-L under uncertainty

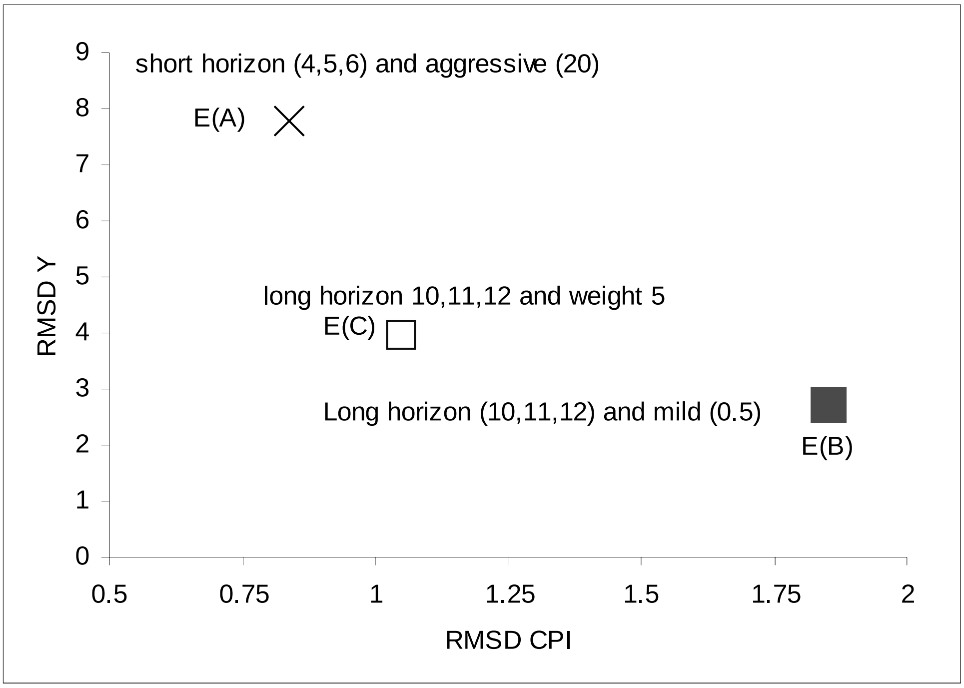


Table 4 lists the expected RMSD values. By calculating the relative changes in output variability over the changes in inflation variability, we can get an idea of what a central bank's preferences would have to look like before the less-robust rule A would be preferred.

Table 4: Expected values for policy rules under FPS-L

					Relative weight needed on CPI vs weight on Y		
Rule	**Weight θ**	**Horizon**	**E(RMSD CPI)**	**E(RMSD Y)**	**A>B**	**A>C**	**C>B**
A	20	4	0.84	7.79	~5x	~18x	–
B	0.5	10	1.85	2.75	–	–	–
C	5	10	1.05	3.97	–	–	~1.5x

As a benchmark, the preference set in Tetlow, von zur Muehlen, and Finan (1999) has been adopted, where a "conservative" preference is one that places three times as much weight on inflation variability over output variability. "Liberal" preferences place three times as much weight on output variability over inflation variability. The results suggest that, in this particular case, a central bank would need to have ultra-

[16] Given time constraints, it has not been possible to calculate an expected frontier for the FPS and FPS-S cases. This will be left for future work.

conservative preferences to prefer the less-robust rule A over rule B or C. However, what could be deemed as a 'reasonable' preference of 1.5, a central bank may prefer rule C to B. But it is still the case that both these rules are very forward looking.

The implications of these results for the choice of policy rules is not entirely clear. Policy makers are more likely to achieve outcomes closer to what they expect by using a less aggressive and more forward-looking rule. However, more aggressive and shorter horizon rules do relatively better at controlling inflation even though the actual results may turn out to be significantly different from expectations. This decision will come down to a central bank's preferences. For the case considered above, a central bank would need to have very conservative preferences to prefer a less robust rule. This may not necessarily be the case for the other two versions of the FPS model, which will be examined in later work. Nevertheless, the one strong result from this analysis is that forward-looking rules are more robust under uncertainty. This is the same result as in Drew and Hunt (1999) where, even under uncertainty that implies inflation forecasting errors, it is still better to be forward looking.

5. The efficient frontiers under model misspecification

In this section, transmission lag uncertainty is examined from an inflation forecasting perspective. There will always be a degree of uncertainty over the 'true' transmission lag is. This being the case, is it better for a central bank to overestimate the lag or underestimate the lag when it is forecasting inflation? By underestimating the transmission lag, a central bank will tend to behave as if inflation is easier to control than it really is. The effect of this type of mistake is to make the policy response less aggressive than would be the case if the central bank knew the truth. Overestimating the transmission lag will have the opposite effect. That is, the central bank behaves as if inflation is harder to control than it really is. The typical policy response will be more aggressive than would be the case if the central bank knew the truth.

Efficient frontiers are traced out for the six uncertainty cases and compared to the relevant no-uncertainty case. There are three cases where the transmission lag is underestimated: (i) L/S, (ii) L/N, and (iii) N/S. The frontiers for L/S and L/N are compared to the FPS-L frontier, while the N/S frontier is compared to the FPS frontier.

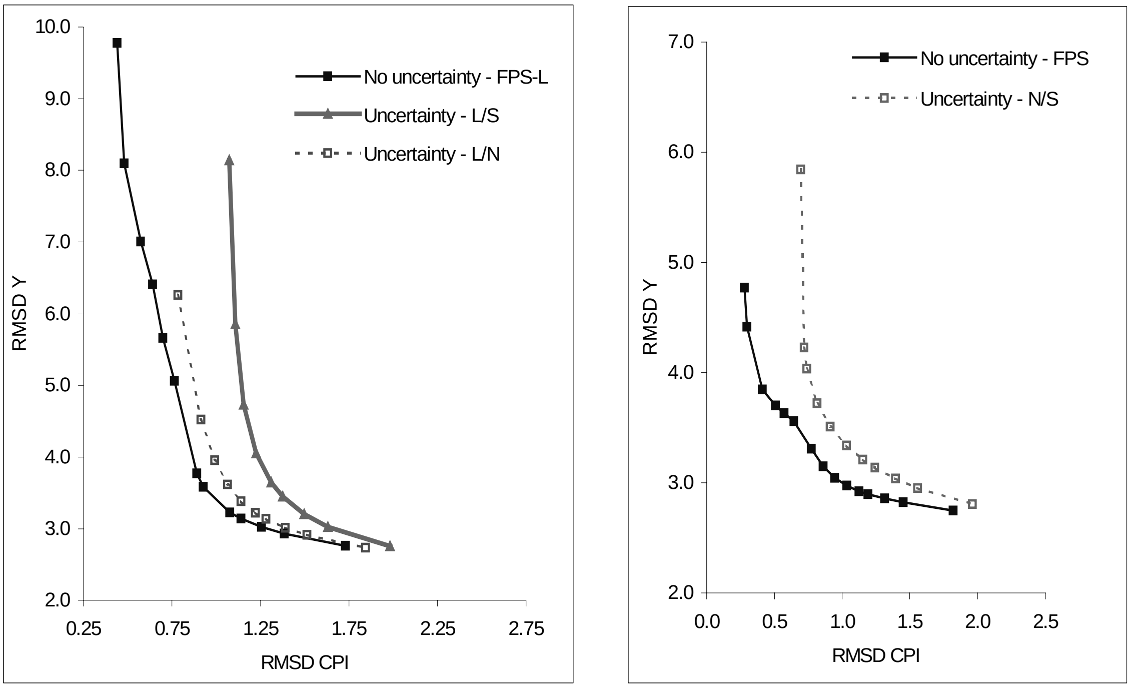
The three cases where the transmission lag is overestimated are: (iv) S/N, (v) S/L, and (vi) N/L. The S/N and S/L frontiers are compared to the FPS-S frontier while the N/L frontier is compared to the FPS frontier. For the cases where the true model is specified by FPS-S (cases S/N and S/L), the stochastic experiments were conducted with the central bank targeting domestic goods price inflation rather than CPI inflation.[17] Problems were encountered in the experiments under CPI inflation targeting because, with the short transmission lag, the exchange rate was having too strong an impact on the variability of CPI inflation resulting in many simulation experiments crashing. In FPS, inflation in domestic goods prices excludes the direct exchange rate effects. By targeting a less volatile measure of inflation, the simulations were able to produce more inflation/output variability outcomes.

5.2 Results

[17] For a more complete analysis of the difference between CPI targeting and domestic price targeting, see Conway et al (1998) and Cassino et al (1999).

Figure 5 plots the efficient frontiers for the three cases when the transmission lag has been underestimated. The summary statistics for these frontiers are listed in appendix 2.

Figure 5: The efficient frontiers when the transmission lag is underestimated



The results show that, relative to when the central bank knows the truth, the stabilisation properties of IFB rules deteriorate when the central bank underestimates the transmission lag – particularly with respect to inflation variability. Table 5 compares the summary statistics for several rules on the L/S and FPS-L frontiers. The common feature is the higher RMSD values for CPI inflation and output (Y), while the average quarterly change in interest rates is smaller, as measured by the mean absolute change (MAC) statistic. These statistics support the story that if the central bank underestimates the lag and believes inflation to be easier to control, the typical policy responses are less aggressive than would be the case if the central bank knew the truth. As a result of the insufficient policy response, inflation tends to get away a bit more and becomes more ingrained into inflation expectations. Relatively larger output losses are then required to unwind the effect of this policy error to bring inflation back to target due to the asymmetry in the inflation process.

Table 5: Summary statistics for a selection of IFB rules on the L/S and FPS-L frontiers

Weight θ	Horizon i	RMSD CPI	RMSD Y	RMSD RN	MAC RN	AR(1) RN	RMSD Z
No uncertainty – FPS-L							
7.0	10	0.89	3.77	9.61	644	0.78	6.29
5.0	10	0.93	3.58	7.52	466	0.84	5.91
2.5	10	1.08	3.23	5.00	272	0.91	5.25
Uncertainty – L/S: underestimating the transmission lag							
7.0	10	1.11	5.85	6.99	334	0.94	9.02
5.0	10	1.15	4.73	5.98	260	0.94	6.76
2.5	10	1.31	3.65	5.02	177	0.96	4.59

Figure 6: The efficient frontiers when the transmission lag is overestimated

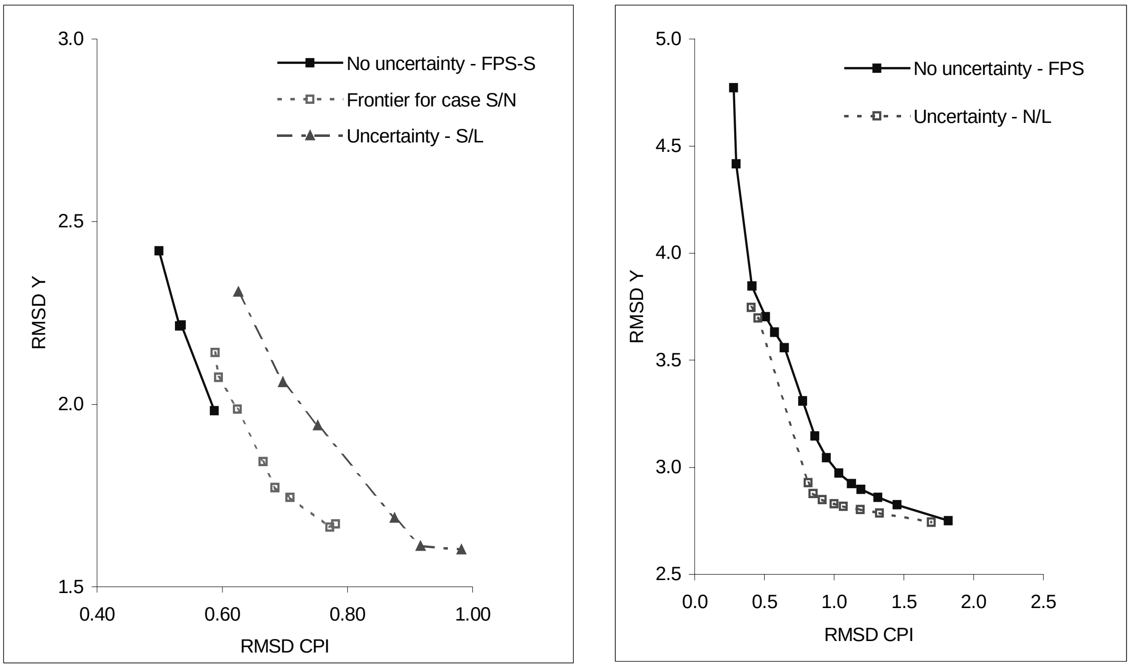


Figure 6 plots the efficient frontiers for the cases when the central bank overestimates the transmission lag. The stabilisation properties appear to improve in one or both dimensions in these cases. Comparing the N/L frontier with the FPS frontier, the N/L is marginally closer to the origin. Relative to the FPS-S frontier, inflation variability worsens slightly, but output variability improves under the S/N and S/L frontiers. The conclusion from these results is that it is better to overestimate the transmission lag and believe inflation is harder to control than underestimate the lag and believe inflation is easier to control. Why is this the case?

The policy error from thinking inflation is harder to control is less costly to unwind than the error from thinking inflation is easier to control. Under the first type of error, the typical policy response is more aggressive than would be the case if the central bank knew the truth – the MAC in interest rate is higher (see table 6). This error, however, is quickly unwound in later in later periods when the central bank sees actual inflation falling faster than expected. Table 6 shows that the persistence in interest rates falling when this mistake is made, as measured by the AR(1) coefficient.

The error from thinking inflation is easier to control takes longer to unwind and incurs greater output losses because inflationary pressures become more ingrained into inflation expectations and because of the asymmetry in the Phillips curve. Table 5 shows that the persistence in the level of interest rates increases when this type of mistake has been made.

Table 6: Summary statistics for when the transmission lag is specified by FPS-S and when the central bank incorrectly assumes it is FPS (S/N)

Weight θ	Horizon *i*	RMSD PDOT	RMSD CPI	RMSD Y	RMSD RN	MAC RN	AR(1) RN
No uncertainty – FPS-S							
3.5	1	0.79	0.50	2.42	8.11	531	0.81
5.0	2	0.75	0.53	2.22	8.48	637	0.74
7.0	2	0.69	0.53	2.21	10.11	797	0.68
Uncertainty: overestimating the transmission lag – S/N							
3.5	1	0.67	0.62	1.99	9.14	677	N/av
5.0	2	0.70	0.68	1.77	10.38	906	0.60
7.0	2	0.67	0.71	1.75	12.79	1197	0.50

This result parallels somewhat the findings in Shuetrim and Thompson (1999). In that paper, uncertainty about the persistence of the economy and policy made the optimal policy response more aggressive. The authors argued that overshooting in the target variables was less costly than undershooting. For example, if the target variables overshoot their expected mark, it must be the case that the economy is less persistent than expected. This overshooting could then be unwound rapidly in later periods. If, on the other hand, the target variables undershoot, then persistence must be higher than expected. However, any undershooting would erode more slowly and hence, incur greater cost. A policy maker aware of the uncertainty about model persistence would take this asymmetry into account and move policy more aggressively. This would ensure that outcomes would be closer to target if the economy was more persistent than expected at the cost of forcing outcomes further from target if model persistence was less than expected. Overall, this strategy would lower expected losses because those outcomes furthest from target could be unwound the quickest.

There are other interesting features of these results that are worth discussing. The intuitive and standard result is that, relative to knowing the truth, macroeconomic performance tends to deteriorate when policy is based on an incorrect information set. However, the results shown in figure 5 suggest that, relative to knowing the truth, better outcomes may be achieved if the central bank is misinformed and overestimates the transmission lag.

In these stochastic experiments, stronger policy responses can result in better outcomes because the shocks that hit the model economy tend to be serially correlated over time. The central bank, however, is unaware of this persistence when setting policy. Hence, a stronger policy response to persistent shocks will dampen output cycles more effectively. This would lower the RMSD of output and, CPI inflation variability as well, via the output gap channel. This appears to be what is happening in the case N/L. As shown in figure 6, the resulting misinformed N/L frontier is slightly closer to the origin than the no-uncertainty FPS frontier. In this case, making an error on the degree of persistence in the economy corrects somewhat the error of underestimating the persistence in stochastic disturbances.

However, the benefits to CPI inflation variability from lower output variability only exist up to a point. By moving interest rates around by more, exchange rate variability rises. After a certain point, the effect of additional exchange rate variability outweighs the effect from lower output variability. This appears to be what is happening in the S/N and S/L cases – output variability is lower, but CPI inflation variability is higher. For these particular cases, the decision on which frontier is better will depend on a central bank’s preferences. For example, a central bank will prefer the misinformed S/N frontier over the no-uncertainty FPS-S frontier if it places around twice as much weight on output stabilisation over inflation stabilisation, i.e. less conservative preferences. However, for these cases, while the RMSD of CPI inflation is relatively higher, the RMSD of domestic goods price inflation that excludes direct exchange rate effects (PDOT) is relatively lower (see table 6).

I would like to make two further points. The first is to note that the results in this section are not a case for simply being more aggressive with policy responses. It is more a case for overestimating the transmission lag, or more specifically, behaving as if inflation is harder to control than it really is. In other words, aggression is not a substitute for believing inflation is relatively harder to control. Using a more aggressive policy rule but knowing the correct transmission lag will not produce the same results as using a less aggressive rule and overestimating the lag. The key difference is that the underlying information set that policy decisions are based on are different. By believing inflation is harder to control, it appears that the central bank is compensating somewhat, the fact that it does not know about the serial correlation in the stochastic disturbances.

To illustrate this point further, the stochastic simulation experiment for the case S/N has been re-run. This time, however, an interest rate smoothing term was added to the policy reaction function. The smoothing term reduces the quarter-to-quarter variability in the short-term nominal interest rate. The results for several IFB rules from the misinformed S/N case with the smoothing constraint are compared with the no-uncertainty FPS-S case in table 7.

Table 7: Summary statistics for FPS-S and S/N with smoothing constraint

Weight θ	Horizon i	RMSD PDOT	RMSD CPI	RMSD Y	RMSD Z	RMSD RN	MAC RN	AR(1) RN
No uncertainty– FPS-S								
3.5	1	1.27	0.50	2.42	6.66	8.11	531	0.81
5	2	1.23	0.53	2.22	6.64	8.48	637	0.74
7	2	1.17	0.53	2.21	6.34	10.11	797	0.68
Uncertainty: overestimating the transmission lag – S/N BUT with smoothing constraint								
3.5	1	1.17	0.60	2.19	7.19	8.26	496	0.84
5	2	1.14	0.66	1.89	6.68	8.79	618	0.77
7	2	1.09	0.69	1.83	6.96	10.57	805	0.70

For these rules, the smoothing constraint has brought the policy responses closer together as seen by the RMSD, MAC and persistence in the short rate, as measured by the AR(1) statistic. Even though the average policy responses are now similar, by responding to an information set that is telling the central bank inflation is harder to control, PDOT and output variability are lower. CPI inflation variability still remains higher. These results may also be due to the asymmetry in the Phillips curve. Later work will examine these issues more fully. Nevertheless, the results do provide support for behaving as if inflation is relatively harder to control, and suggests that these results are not a by-product of simply more aggressive policy responses.

The final result I want to mention is that, when the central bank overestimates the transmission lag, persistence may be a substitute for aggressiveness. This result can be seen more clearly when the policy rules are compared for S/N cases with and without the smoothing constraint. The summary statistics are presented in table 8.

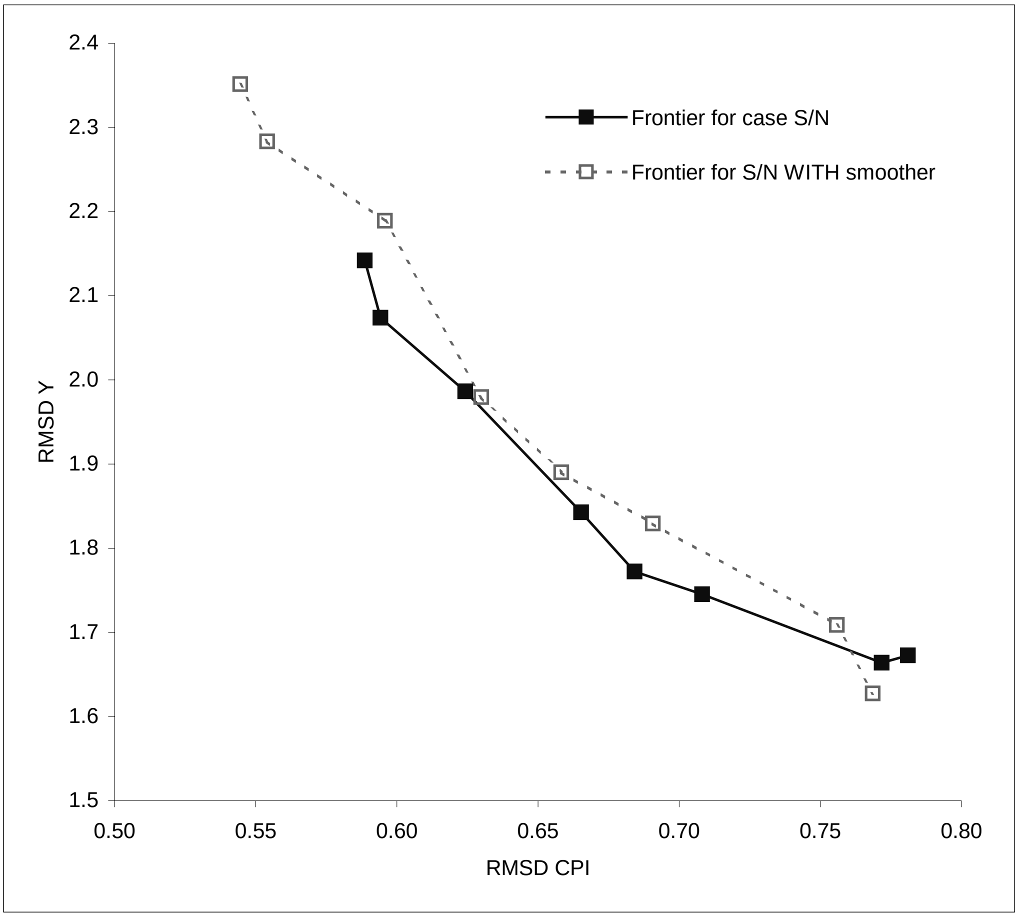
Table 8: Summary statistics for policy rules for case S/N with and without an interest rate smoothing constraint

Weight θ	**Horizon** i	**RMSD PDOT**	**RMSD CPI**	**RMSD Y**	**RMSD RN**	**MAC RN**	**AR(1) RN**
Uncertainty: overestimating the transmission lag – S/N							
3.5	1	0.67	0.62	1.99	9.14	677	n/av
5	2	0.70	0.68	1.77	10.38	906	0.60
7	2	0.67	0.71	1.75	12.79	1197	0.50
20	4	0.81	0.78	1.67	14.47	1662	0.22
S/N but WITH an interest rate smoothing constraint							
3.5	1	0.68	0.60	2.19	8.26	496	0.84
5	2	0.69	0.66	1.89	8.79	618	0.77
7	2	0.65	0.69	1.83	10.57	805	0.70
20	4	0.79	0.77	1.63	10.81	1001	0.54

While the smoothing constraint has dampened the aggressiveness and increased the persistence of policy, the 'before-and-after' picture for inflation and output variability is little changed. The resulting efficient frontier is plotted in figure 8 and the positions of the two frontiers are very similar. This result parallels somewhat other research that has shown that policy persistence can be good in models of the US economy because the long-term interest rate has a significant effect on behaviour.[18] Persistent changes in short-term rates lead to larger movements in long-term rates. The result here is interesting since, in the FPS model, long rates have less direct effect on economic behaviour than most US models. However, the result here that 'persistence is a substitute for aggressiveness' is not a general result. For example, when the central bank underestimates the transmission lag, the stabilisation properties of efficient IFB rules deteriorate further when the smoothing constraint has been applied. This issue remains to be more fully examined in later work.

[18] See, for example, Levin A., V. Weiland, and J. C. Williams (1998) "Robustness of Simple Monetary Policy Rules Under Model Uncertainty", NBER Working paper 6570

Figure 7: The efficient frontiers for S/N with and without a smoothing constraint



6. Summary

There will always be a degree of uncertainty over the what the correct length of the transmission lag is. The implication for monetary policy of this type of uncertainty was examined from two perspectives. The first examined the issue of choosing which type of efficient IFB rule to use under uncertainty. The results indicate that less aggressive and more forward-looking rules were more robust than more aggressive and less forward-looking rules. That is, under transmission lag uncertainty, policymakers are more likely to achieve outcomes that are closer to what they expect by using less aggressive and more forward-looking IFB rules. However, the overall implication for monetary policy was less clear. The results also showed that less-robust rules tend to do better at stabilising inflation regardless of what the actual transmission lag is and regardless of what the central bank believes the transmission lag to be. However, to put some perspective on this trade-off, under the particular case considered, only an extremely conservative policymaker would not prefer a robust rule – that is, a rule that is quite forward looking with a moderate response coefficient.

The second aspect examined transmission lag uncertainty from an inflation forecasting perspective. In particular, the question asked was, given that there will always be a degree of uncertainty surrounding the length of the transmission lag, is it better for the central bank to underestimate the transmission lag or overestimate the lag? The results suggested that it would be better to overestimate the transmission lag. If the central bank underestimates the lag, it believes inflation is relatively easier to control. The initial policy responses tend to be insufficient to counter actual inflationary pressures. As a result, macroeconomic performance tends to deteriorate. To unwind the effect of this mistake requires relatively larger output losses because inflationary pressures become more ingrained into inflation expectations and the asymmetry in the Phillips curve.

If, on the other hand, the central bank overestimates the lag, it believes inflation is relatively harder to control. The typical policy response is relatively more aggressive and as a result, the central bank is able to counter inflationary pressures earlier and do a relatively better job at stabilising the economy. Consistent with Shuetrim and

Thompson (1999), overly-aggressive policy actions are less costly to unwind than insufficiently-aggressive policy actions. That is, the error made from thinking inflation is harder to control can be unwound quickly in later periods when the central bank sees actual inflation falling by more than expected. The error from thinking inflation is easier to control is only unwound more slowly and at a greater cost.

Interestingly, the results also showed that, relative to knowing the truth, when the central bank is misinformed and believes inflation is relatively harder to control, better outcomes may be achieved depending on preferences. This result was not simply a by-product of more aggressive policy responses. When the aggressiveness of policy was constrained, it was still the case that potentially better outcomes could be achieved. One possible explanation is that making an error on the degree of persistence in the economy is compensating the error from underestimating the persistence in the stochastic disturbances. This result provided further support for being prudent and behaving as if inflation is relatively harder to control.

References:

Amano, R., D. Coletti and T. Macklem (1999). "Monetary rules when economic behaviour changes." To appear in Benjamin Hunt and Adrian Orr (eds.) *Monetary Policy Under Uncertainty* (Wellington, New Zealand).

Berk, J. (1997) " Monetary Transmission: What Do We Know and How Can We Use It", *Staff Report no. 15/1997*, De Nederlandsche Bank

Black, R., V. Cassino, A. Drew, E. Hansen, B. Hunt, D. Rose and A. Scott (1997), "The Forecasting and Policy System: the core model", Reserve Bank of New Zealand *Research Paper* No. 43.

Blinder, A. (1997), "What Central Bankers Could Learn from Academics – and Vice Versa", *Journal of Economic Perspectives*, v.11 pp. 3 – 19

Brainard, W. (1967), "Uncertainty and the effectiveness of policy", *American Economic Review,* Vol. 57: 411-425.

Britton, E. and J. Whitley (1997) "Comparing the Monetary Transmission Mechanism in France, Germany and the United Kingdom: Some Issues and Results", *Quarterly Bulletin*, Bank of England, May pp. 152 – 162

Caplin, A. and J. Leahy (1996) "Monetary Policy as a Process of Search", *American Economic Review*, v. 86 pp. 689-702

Cassino, V., A. Drew, and S. McCaw (1999) "Targeting alternative measures of inflation under uncertainty about inflation expectations and exchange rate pass-through" Paper presented at 1999 BIS meeting of central bank model builders and econometricians.

Conway, P., A. Drew, B. Hunt, and A. Scott. (1998), "Exchange rate effects and inflation targeting in a small open economy: a stochastic analysis using FPS", *BIS Conference Papers,* Vol. 6.

Drew, A. and B. Hunt (1998), "The forecasting and policy system: stochastic simulations of the core model". Reserve Bank of New Zealand *Discussion Paper* G98/6.

Drew, A. and B. Hunt (1999) "Efficient simple policy rules and the implications of potential output uncertainty" forthcoming *Journal of Economics and Business* Special edition on Money and Monetary Policy in a Changing World.

Frankel, J. and K. Rockett (1986) "International Macroeconomic Policy Coordination When Policymakers Do Not Agree on the True Model", *American Economic Review*, v.78 pp. 318-340

Ghosh, A. and P. Masson (1988) "International Policy Coordination in a World with Model Uncertainty", *Staff Papers*, International Monetary Fund, v. 35 pp. 230-58

Ghosh, A. and P. Masson (1991) "Model Uncertainty, Learning and the Gains from Coordination", *American Economic Review*, v. 81 pp. 465-479

Gruen, D., J. Romalis and N. Chandra (1997) "The Lags of Monetary Policy", in *Monetary Policy and the Inflation Process*, Bank for International Settlements, 1997

Haldane, A. G. (1997) "Designing Inflation Targets", Paper presented at the Reserve Bank of Australia's conference on "Monetary Policy and Inflation Targeting, July 1997

Haldane A. and N. Batini (1998). "Forward-Looking Rules for Monetary Policy." In J.B. Taylor (ed), *Monetary Policy Rules*. Chicago: University Press for NBER.

Isard, P., D. Laxton and A. Eliasson (1998). "Inflation Targeting with NAIRU Uncertainty and Endogenous Policy Credibility." Paper presented at the Fourth Conference on Computational Economics, Cambridge, United Kingdom.

Laxton, D., Rose, D., and Tetlow, B. (1994) "Monetary Policy, Uncertainty, and the Presumption of Linearity", Bank of Canada *Technical Report* No. 63

Mauskopf, E. (1990) "The Transmission Channels of Monetary Policy: How have they Changed?" *Federal Reserve Bulletin*, December pp. 985-1008

Mosser, P. (1992) "Changes in Monetary Policy Effectiveness: Evidence from Large Macroeconometric Models", *Quarterly Review*, Federal Reserve Bank of New York, Spring pp. 36-49

Onatski, A and J. H. Stock (1999) "Robust Monetary Policy Under Model Uncertainty is a Small Model of the U.S. Economy", paper presented at the SIEPR conference on Monetary Policy.

Shuetrim, G and C. Thompson (1999) "The Implications of Uncertainty for Monetary Policy", to appear in Benjamin Hunt and Adrian Orr (eds.) *Monetary Policy Under Uncertainty* (Wellington, New Zealand)

Svensson, L.E.O. (1997),. "Inflation Targeting in an Open Economy: Strict or Flexible Inflation Targeting?", *Discussion Paper G97/8,* Reserve Bank of New Zealand

Taylor, J. (1979), "Estimation and Control of a Macroeconomic Model with Rational Expectations",. *Econometrica* 47:1267-86.

Tetlow, R., P. von zur Muehlen, and F. S. Finan (1999) "Learning and the Complexity of Monetary Policy Rules" to appear in Benjamin Hunt and Adrian Orr (eds.) *Monetary Policy Under Uncertainty* (Wellington, New Zealand)

Tinsley, P.A. (1993), "Fitting both data and theories: polynomial adjustment costs and error-correction decision rules", Unpublished paper. Division of Statistics and Research, Board of Governors of the Federal Reserve System, Washington.

Appendix 1: The summary statistics for the efficient IFB rules derived under certainty

Weight, θ_i	Target horizon, i	RMSDCPI Inflation	RMSDY Output	RMSDRN Interest rate	RMSDZ Exchange rate
FPS (Standard Lag)					
20	**1**	0.28	4.77	16.26	8.12
20	**2**	0.30	4.42	14.62	7.50
20	**4**	0.41	3.85	10.71	6.78
10	**4**	0.51	3.70	8.37	6.47
7	**4**	0.57	3.63	7.41	6.29
5	**4**	0.64	3.56	6.61	6.10
10	**10**	0.77	3.31	6.79	6.08
7	**10**	0.86	3.15	5.53	5.66
5	**10**	0.94	3.04	4.78	5.37
3.5	**10**	1.03	2.97	4.26	5.13
2.5	**10**	1.13	2.92	3.89	4.96
2	**10**	1.19	2.90	3.70	4.86
1.4	**10**	1.31	2.86	3.44	4.72
1	**10**	1.45	2.82	3.25	4.61
0.5	**10**	1.82	2.75	3.06	4.43
FPS-S (Short Lag)					
20	**1**	0.17	3.02	8.95	7.13
20	**2**	0.22	2.86	9.05	7.18
10	**2**	0.30	2.76	7.62	6.85
7	**2**	0.36	2.72	6.90	6.64
10	**4**	0.49	2.43	6.93	6.65
20	**10**	0.57	2.31	8.72	6.55
10	**10**	0.62	2.32	5.94	5.90
7	**6**	0.71	2.26	4.89	5.41
FPS-L (Long Lag)					
20	**2**	0.44	9.78	25.98	13.31
20	**4**	0.48	8.10	17.16	10.75
10	**4**	0.57	7.00	12.98	9.19
7	**4**	0.64	6.41	11.13	8.35
7	**6**	0.70	5.66	9.36	7.79
5	**6**	0.76	5.06	7.99	7.06
7	**10**	0.89	3.77	9.61	6.29
5	**10**	0.93	3.58	7.52	5.91
2.5	**10**	1.08	3.23	5.00	5.25
2	**10**	1.14	3.14	4.53	5.10
1.4	**10**	1.26	3.02	3.97	4.89
1	**10**	1.39	2.93	3.60	4.73
0.5	**10**	1.73	2.76	3.19	4.50

Appendix 2: Summary statistics for the cases where the central bank makes a mistake about the transmission lag

The actual transmission lag is specified by FPS-L							
WEIGHT	HORIZON	RMSDCPI	RMSDY	RMSDRN	RMSDZ	RMSDPDOT4	MACRN
No uncertainty – FPS-L							
20.00	2	0.44	9.78	25.98	13.31	3.09	1749
20.00	4	0.48	8.10	17.16	10.75	2.65	1161
10.00	4	0.57	7.00	12.98	9.19	2.40	767
7.00	4	0.64	6.41	11.13	8.35	2.28	618
7.00	6	0.70	5.66	9.36	7.79	2.03	457
5.00	6	0.76	5.06	7.99	7.06	1.91	387
7.00	10	0.89	3.77	9.61	6.29	1.43	644
5.00	10	0.93	3.58	7.52	5.91	1.48	466
2.50	10	1.08	3.23	5.00	5.25	1.58	272
2.00	10	1.14	3.14	4.53	5.10	1.62	236
1.40	10	1.26	3.02	3.97	4.89	1.70	192
1.00	10	1.39	2.93	3.60	4.73	1.79	160
0.50	10	1.73	2.76	3.19	4.50	2.06	116
Uncertainty: underestimating the lag - L/S							
10.0	10	1.07	8.14	9.12	13.85	2.98	477
7.0	10	1.11	5.85	6.99	9.02	2.39	334
5.0	10	1.15	4.73	5.98	6.76	2.12	260
3.5	10	1.22	4.05	5.38	5.39	1.98	210
2.5	10	1.31	3.65	5.02	4.59	1.94	177
2.0	10	1.38	3.45	4.86	4.20	1.94	159
1.4	10	1.50	3.20	4.65	3.74	1.97	137
1.0	10	1.63	3.02	4.51	3.45	2.04	120
0.5	10	1.98	2.76	4.34	3.17	2.29	96
Uncertainty: underestimating the lag - L/N							
20.0	10	0.78	6.26	8.20	14.26	2.01	749
10.0	10	0.91	4.52	6.41	7.91	1.81	387
7.0	10	0.99	3.95	5.78	6.20	1.74	302
5.0	10	1.06	3.61	5.39	5.23	1.71	253
3.5	10	1.14	3.38	5.10	4.58	1.71	217
2.5	10	1.22	3.22	4.91	4.14	1.74	190
2.0	10	1.28	3.13	4.80	3.91	1.77	174
1.4	10	1.39	3.01	4.66	3.60	1.83	152
1.0	10	1.51	2.91	4.55	3.38	1.90	134
0.5	10	1.84	2.73	4.39	3.13	2.16	105

The actual transmission lag is specified by the standard FPS model							
WEIGHT	**HORIZON**	**RMSDCPI**	**RMSDY**	**RMSDZ**	**RMSDPDOT4**	**RMSDRN**	**MACRN**
No Uncertainty – FPS							
20.0	1	0.28	4.77	8.12	1.42	16.26	1204
20.0	2	0.30	4.42	7.50	1.37	14.62	1187
20.0	4	0.41	3.85	6.78	1.32	10.71	935
10.0	4	0.51	3.70	6.47	1.36	8.37	654
7.0	4	0.57	3.63	6.29	1.38	7.41	541
5.0	4	0.64	3.56	6.10	1.41	6.61	450
10.0	10	0.77	3.31	6.08	1.29	6.79	389
7.0	10	0.86	3.15	5.66	1.34	5.53	303
5.0	10	0.94	3.04	5.37	1.39	4.78	253
3.5	10	1.03	2.97	5.13	1.45	4.26	216
2.5	10	1.13	2.92	4.96	1.52	3.89	189
2.0	10	1.19	2.90	4.86	1.57	3.70	173
1.4	10	1.31	2.86	4.72	1.66	3.44	150
1.0	10	1.45	2.82	4.61	1.77	3.25	131
0.5	10	1.82	2.75	4.43	2.08	3.06	102
Uncertainty: underestimating the lag - N/S							
20.0	2	0.70	5.85	8.40	1.98	13.09	711
10.0	4	0.72	4.23	6.98	1.69	7.90	492
10.0	10	0.74	4.04	6.53	1.43	7.79	394
7.0	10	0.82	3.72	6.01	1.46	6.30	307
5.0	10	0.91	3.51	5.61	1.51	5.32	250
3.5	10	1.03	3.34	5.27	1.56	4.59	205
2.5	10	1.15	3.21	5.02	1.63	4.08	174
2.0	10	1.24	3.14	4.88	1.68	3.82	157
1.4	10	1.39	3.04	4.69	1.78	3.49	134
1.0	10	1.56	2.95	4.56	1.89	3.28	118
0.5	10	1.96	2.81	4.38	2.22	3.10	94
Uncertainty: overestimating the lag - N/L							
10.0	4	0.41	3.75	6.70	1.24	9.70	790
7.0	4	0.45	3.70	6.48	1.27	8.23	622
7.0	10	0.82	2.93	6.38	1.12	10.48	775
5.0	10	0.85	2.88	5.91	1.19	7.60	517
3.5	10	0.92	2.85	5.57	1.27	5.87	366
2.5	10	1.00	2.83	5.30	1.36	4.87	281
2.0	10	1.07	2.82	5.16	1.42	4.40	241
1.4	10	1.19	2.80	4.96	1.53	3.85	193
1.0	10	1.33	2.79	4.79	1.65	3.50	160
0.5	10	1.70	2.74	4.54	1.97	3.12	114

The actual transmission lag is specified by FPS-S							
WEIGHT	**HORIZON**	**RMSDCPI**	**RMSDY**	**RMSDZ**	**RMSDPDOT4**	**RMSDRN**	**MACRN**
No Uncertainty– FPS-S							
3.5	1	0.50	2.42	6.66	0.79	8.11	531
7.0	2	0.53	2.21	6.64	0.69	10.11	797
5.0	2	0.53	2.22	6.34	0.75	8.48	637
20.0	4	0.59	1.98	6.14	0.71	9.35	789
Uncertainty: overestimating the lag – S/N							
2.0	1	0.59	2.14	6.41	0.82	6.58	420
2.5	1	0.59	2.07	6.61	0.75	7.50	510
3.5	1	0.62	1.99	6.92	0.67	9.14	677
3.5	2	0.67	1.84	6.23	0.75	8.37	674
5.0	2	0.68	1.77	6.48	0.70	10.38	906
7.0	2	0.71	1.75	6.75	0.67	12.79	1197
10.0	4	0.77	1.66	5.62	0.83	9.79	981
20.0	4	0.78	1.67	5.85	0.81	14.47	1662
Uncertainty: S/N with smoothing constraint							
2.0	1	0.54	2.35	6.69	0.85	6.16	309
2.5	1	0.55	2.28	6.89	0.77	6.94	376
3.5	1	0.60	2.19	7.19	0.68	8.26	496
3.5	2	0.63	1.98	6.42	0.74	7.26	465
5.0	2	0.66	1.89	6.68	0.69	8.79	618
7.0	2	0.69	1.83	6.96	0.65	10.57	805
10.0	4	0.76	1.71	5.74	0.82	7.89	630
20.0	4	0.77	1.63	5.95	0.79	10.81	1001
Uncertainty: overestimating the lag – S/L							
1.4	1	0.63	2.31	6.73	0.83	5.75	321
1.4	2	0.70	2.06	6.15	0.85	5.47	340
2.0	2	0.75	1.94	6.59	0.73	6.96	486
2.5	4	0.88	1.69	5.64	0.89	6.59	515
3.5	4	0.92	1.61	5.92	0.86	8.37	713
5.0	4	0.98	1.60	6.34	0.86	11.14	1030