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## Abstract

In recent years, there has been a lot of interest in Taylor-type rules. Evidence in the literature suggests that Taylor-type rules are optimal in a number of models and are fairly robust across different models. The reaction function in the Bank of Canada's Quarterly Projection Model (QPM) is an inflation-forecast-based (IFB) rule. A number of studies have suggested, however, that the optimality of IFB rules is very model-specific. Given this and concerns about model uncertainty, it seems logical to assess the performance of Taylor-type reaction functions in QPM. Therefore, we compare QPM's IFB rule with a simple Taylor rule as well as with two rules that include open-economy elements. Overall, our results suggest that Taylor-type rules do not perform well in QPM compared with the base-case IFB rule, since they are associated with significantly higher variabilities of inflation, output, and interest rates. However, of the Taylor-type rules considered, we find that a simple rule with a coefficient of 2 on the contemporaneous inflation gap (versus 0.5 in Taylor's original rule) and a coefficient of 0.5 on the output gap is the most appropriate. Furthermore, the gains from using open-economy rules seem to be limited.

*JEL classification: E5, E52*
*Bank classification: Monetary policy framework; Uncertainty and monetary policy; Economic models*

## Résumé

Les règles de Taylor suscitent un regain d'intérêt depuis quelques années. D'après la littérature empirique, ces règles seraient optimales dans un certain nombre de modèles et assez peu sensibles aux changements de spécification. La fonction de réaction retenue dans le Modèle trimestriel de prévision (MTP) de la Banque du Canada est une règle fondée sur l'inflation prévue. Un certain nombre d'études indiquent toutefois que l'efficacité des règles de ce genre dépend beaucoup du modèle. À la lumière de ce constat et compte tenu de l'incertitude relative à la formulation appropriée du modèle, il paraît logique d'évaluer l'efficacité des fonctions de réaction inspirées de règles de Taylor dans le MTP. Les auteurs comparent donc la règle actuelle basée sur l'inflation prévue à une règle de Taylor simple ainsi qu'à deux autres règles adaptées à un cadre d'économie ouverte. Les règles de Taylor se comportent moins bien que la règle utilisée présentement dans le scénario de base du MTP : elles s'accompagnent en effet d'une variabilité nettement plus élevée de l'inflation, de la production et des taux d'intérêt. Parmi les règles de Taylor examinées, celle qui donne les meilleurs résultats est une règle simple où le coefficient de l'écart d'inflation contemporain est 2 (plutôt que 0,5 dans la règle proposée initialement par Taylor) et le coefficient de l'écart de production est 0,5. En outre, l'emploi de règles adaptées à un cadre d'économie ouverte ne semble procurer que des gains limités.

*Classification JEL : E5, E52*
*Classification de la Banque : Cadre de la politique monétaire; Incertitude et politique monétaire; Modèles économiques*

# 1. Introduction

The reaction function in the Quarterly Projection Model (QPM) used by the Bank is an inflation-forecast-based rule where the monetary authority adjusts the short-term interest rate based on the difference between expected inflation in the future and the inflation target, and the current output gap.[1] A number of studies have suggested, however, that the optimality of inflation-forecast-based (IFB) rules is very model-specific. Small changes in the model can imply quite different coefficient values for the optimal rule. Since any macroeconomic model is at best an approximation of how the economy works, there will always be questions regarding key relationships such as the monetary transmission mechanism. It is important, therefore, to have a rule that is relatively robust with respect to small changes within a given model as well as robust across models with different assumptions about key features of the economy.

In recent years, there has been a lot of interest in Taylor rules. These rules, based on contemporaneous deviations of inflation from its target and output gaps, seem to explain past movements in policy interest rates reasonably well; i.e., they are useful in helping to describe past policy actions. Evidence in the literature also suggests that Taylor-type rules are optimal in a number of models and are fairly robust across different models. This makes them useful as rules that can indicate how interest rates should be set in the future.

Given their performance in other models and the concerns about model uncertainty, it seems logical to assess the performance of Taylor-type reaction functions in the Bank's projection model. In this paper, therefore, we study Taylor-type rules within QPM. More specifically, we try to find a Taylor rule that performs at least as well as the IFB rule in QPM, and we compare the model properties of a simple Taylor rule with two rules that include open-economy elements. This serves two functions. First, there are a number of questions regarding the exact form of the Taylor rule to use; for example, whether to include open-economy extensions, and how non-linearities of a model affect the performance of the rule. Some investigation of these questions is done by looking at the implications for model properties within QPM. Second, Taylor rules have not been comprehensively evaluated across models that incorporate important features of the Canadian economy. Thus, it is interesting to examine whether Taylor-type rules perform well in models such as QPM.[2]

1. The output gap term has recently been added to the base-case QPM reaction function.
2. "Taylor-type rules" encompass rules based on the original Taylor rule, as well as open-economy extensions.

Of the Taylor-type rules considered, we find that a simple rule with a coefficient of 2 on the contemporaneous inflation gap (versus 0.5 in Taylor's original rule) and a coefficient of 0.5 on the output gap seems to be appropriate. These coefficients were chosen using very general criteria, such as avoiding excessive secondary cycling and trying to match the preferences regarding the aggressiveness of initial policy reactions to the current IFB rule. This second criterion is important, as the current rule incorporates the preferences of a monetary authority.

Overall, however, our results suggest that Taylor-type rules do not perform well in QPM compared to the base-case IFB rule, since they are associated with significantly higher variabilities of inflation, output, and interest rates. This is largely owing to the fact that these rules are not explicitly forward-looking, and are thus less able to provide a smooth policy response to future shocks. The extent to which open-economy extensions of Taylor rules, such as the rule suggested by Ball (1999), do better than the simple Taylor rule appears to be highly dependent on the extent to which temporary exchange rate shocks appear in the data: the higher the exchange rate variability, the greater the gains in decreased output and interest rate variability from adopting an open-economy rule. We find that there are some practical problems, however, in using the Ball (1999) rule, such as measuring the equilibrium exchange rate and having the results be robust to changes in the definition of this equilibrium. Moreover, the Ball rule may not work well in an environment where there is a trend in the equilibrium exchange rate.

This paper should be considered as the first step of a larger project to find a Taylor-type rule that is robust across a variety of models for Canada. To consider model uncertainty, it will be important to collect and develop models of the Canadian economy that have different assumptions regarding the economy's key features. Different kinds of Taylor-type rules could then be evaluated across these models, allowing us to study which rules are most robust.

Section 2 describes the motivation for the paper in depth and briefly reviews some of the literature on robustness and uncertainty.[3] Section 3 summarizes QPM. Section 4 describes how Taylor-type rules are incorporated into QPM, and discusses results from both deterministic and stochastic simulations from QPM. Sections 5 and 6 describe simulation results for the two open-economy rules considered. Section 7 uses counterfactual simulations to consider how to assess the information contained in alternative rules, and section 8 concludes. The appendix discusses the calibration of the stochastic simulations.

3. For a survey of the recent literature on reaction functions, see Armour and Côté (1999–2000).

## 2. Rules, Robustness, and Uncertainty

Endogenous monetary rules provide a useful benchmark for policy implementation. They are usually chosen to reflect certain preferences of the monetary authority regarding, for example, the speed with which inflation should return to target, and average variability of output, inflation, and interest rates. While no central bank implements policy by following a mechanistic rule, the results are nevertheless useful as a benchmark. They also aid in comparisons between various scenarios for exogenous variables, making it easier to identify differences coming from the various shocks rather than those stemming from differences in policy.

The explicitly forward-looking IFB rules are a popular class of monetary rules. Rules based on inflation forecasts make a change in the policy instrument a function of the deviation of a conditional inflation forecast in some future period from the target rate of inflation. One disadvantage, however, of IFB rules is that they are usually not robust across different models. Since the IFB rules typically use model-consistent inflation forecasts, this makes the coefficients sensitive to the structure of the model. A rule that works well in one model may perform poorly in another fairly similar model. This is clearly a major drawback given the extent of model uncertainty. For example, Amano, Coletti, and Macklem (1999) consider robustness by comparing stochastic simulations of IFB rules in different versions of the Canadian Policy Analysis Model (CPAM) that have different assumptions regarding the degree of credibility of policy. They find that, to exploit the potential gains from increased credibility, the monetary authority must recalibrate the IFB rule, and that failure to do so can result in a deterioration in performance.

With concerns about the robustness of IFB rules, simple contemporaneous rules have become very popular, in particular the Taylor rule. Taylor's original rule was estimated, and it modelled deviations of the short-term interest rate from its equilibrium value as a function of the contemporaneous output gap and a contemporaneous inflation gap. It was intended to be a simple operational rule, which captures the key factors affecting inflation. This rule is shown in equation (1):

$$r_t = r^* + 0.5 \cdot (\Pi_t - \overline{\Pi}) + 0.5 \cdot (y_t - y^*) \quad (1)$$

where $r_t$ is the real interest rate, $r^*$ is the equilibrium real interest rate, $\Pi_t - \overline{\Pi}$ is the deviation of the year-over-year inflation rate from the target rate of inflation, and $y_t - y^*$ is the output gap.

A number of studies have compared the performance of Taylor-type rules across different models with the performance of forward-looking rules. Many find that the Taylor-type rules are more robust. For example, Levin, Wieland, and Williams (1999) study the robustness of rules across four different rational expectations models. They find that the optimal Taylor-type rule in all four models is very similar, whereas more complicated rules, including IFB rules, are far less robust. Similarly, work at the Bank by Amano extends the previous work of Amano, Coletti, and Macklem (1999), and finds that, unlike an IFB rule, a Taylor-type rule does not need to be recalibrated to exploit the potential gains from increased credibility.

A number of studies using very simple models, which can be solved analytically, have found that a Taylor-type rule is optimal (i.e., minimizes a specific loss function based on the variabilities of inflation, output, and interest rates). Simple extensions to these models have been developed with the implications for the optimal rule derived. Ball (1999) and Svensson (2000), for example, examine the implications of introducing open-economy effects. Srour (1999) investigates the implications of various kinds of uncertainty for a simple Taylor rule and an open-economy extension. There are some tensions, however, between the optimal Taylor rule literature and the original idea of simple, robust rules. There are clear advantages in starting from simple models that embody the key stylized facts about the economy. The optimal rules in such models have a sound theoretical basis and hopefully will be robust across the class of more complicated models that nevertheless have similar stylized facts as their basis. As further extensions are added to the simple models, however, the optimal rule becomes increasingly complex. At some point, this added complexity will likely conflict with the characteristics of a robust rule, as the variables and coefficient values become more model-specific.

## 3. QPM

QPM is a system of two models: a well-defined, neo-classical, steady-state model (SSQPM), which determines the long-run equilibrium, and a dynamic model, which traces the adjustment path between the starting conditions and the steady state.[4]

Within SSQPM are three key groups of agents: consumers, profit-maximizing firms, and government. Consumer behaviour is modelled on the Blanchard-Weil model of overlapping generations. Consumers have a desired level of wealth, and make decisions on savings and consumption over time to reach that level. Firms determine the capital stock and associated rates of investment. The government sector determines the level of debt and associated levels of government expenditure and taxes. These decisions take place in the context of an open economy,

4. For detailed documentation on QPM and SSQPM, see Black et al. (1994), Armstrong et al. (1995), and Coletti et al. (1996). For a less technical review of QPM and its use at the Bank, see Poloz, Rose, and Tetlow (1994).

where the exchange rate must adjust to ensure that the current account balance is consistent with the flows needed to service any foreign debt.

Key features of QPM are that it is dynamically stable and that the key stocks in the model (government bonds, capital, and net foreign assets) are consistent with the economic theory in SSQPM. The necessary flows are supported by relative price movements, and if a shock affects a stock, the required flows are generated to return the model to its steady state.

QPM is not an estimated model: rather, it is calibrated to reflect empirical evidence and established stylized facts. For example, the model is calibrated to ensure that there is a sacrifice ratio of 3:1 in a disinflation (i.e., in a 1 percentage point disinflation the cumulative output gap is 3 per cent), and a benefit ratio of 1 in an inflation shock. These properties are based on estimations of an asymmetric Phillips curve for the period 1975 to 1991 by Laxton, Rose, and Tetlow (1993).

Within the dynamic model (QPM), a number of important features affect the path of the economy over the short and medium terms. Adjustment of both prices and quantities is assumed to be costly, so there is an intrinsic element to the dynamics. Agents are forward-looking, and their expectations are modelled as a combination of a backward-looking/adaptive component and forward-looking model-consistent values. Changes in the structure of the model or the policy rules, therefore, are incorporated into agents’ expectations. QPM also includes an endogenous fiscal-policy reaction function. The fiscal-policy rule determines government expenditures and taxation based on an exogenously determined target debt-to-GDP ratio.

In QPM, the objective of monetary policy is to control inflation, defined as the year-over-year change in the consumer price index excluding food and energy (CPIXFE).[5] In the base model, monetary policy is implemented through a forward-looking reaction function that adjusts the policy instrument to bring inflation into line with the inflation target. However, in contrast to the Taylor rule, the left-side variable in the reaction function is the yield-spread gap, defined as the difference between the nominal 90-day rate and the nominal 10-year rate (the actual yield spread) and its steady-state value. Both the base-case IFB rule and the transmission mechanism to aggregate demand in QPM are written in terms of the yield spread, as this variable is highly correlated with aggregate demand in Canada. The policy instrument, however, is the 90-day nominal interest rate. Therefore, the monetary authority sets that policy instrument to achieve a desired yield-spread gap, which is determined by looking at the inflation gap 6 to 7 quarters

5. This paper was written before the announcement of the new definition of core inflation for the renewed inflation-control target range (Bank of Canada 2001).

ahead, as well as at the contemporaneous output gap. The inflation target used to construct the inflation gap is the midpoint of the inflation target range. This rule is shown in equation (2):

$$yieldgap_t = \alpha \cdot yieldgap_{t-1} + \beta \cdot \left\{ \sum_{k=6}^{7} \frac{1}{2} (\Pi_{t+k} - \overline{\Pi}_{t+k}) \right\} + \gamma \cdot (y_t - y^*) \quad (2)$$

The degree to which the equation is forward-looking reflects in part the horizon over which it is believed monetary policy can influence inflation in a meaningful way. In other words, the monetary authority wants to assess which shocks are occurring and how they will influence inflation in 18 months' to 2 years' time, and then react accordingly. One alternative method of doing this would be to have an equation that includes contemporaneous values for all the major variables likely to affect future inflation; for example, commodity prices, the exchange rate, the output gap, and rest-of-world shocks. In contrast, an inflation-forecast rule provides a parsimonious way of capturing all of these different effects, since they are reflected in the model-consistent forecast.

## 4. Including Taylor-Type Rules in QPM

Given the concern about model uncertainty and the robustness of reaction functions, this paper compares the performance of Taylor-type rules to QPM's base-case IFB rule. When incorporating a Taylor-type rule into QPM, it was decided to use a rule written in terms of the level of the real interest rate, rather than use a rule in terms of the yield spread, as in the base-case reaction function in QPM. We define real interest rates in the Taylor rule as the nominal 90-day rate deflated by the current period's inflation rate.[6] The equilibrium real interest rate in the Taylor rule is defined as a constant.[7] As in the base-case rule of QPM, the inflation gap is defined in terms of CPIXFE inflation (i.e., the year-over-year increase in the consumer price index excluding food and energy).[8]

6. Nominal interest rates are deflated by an average of CPIXFE and GDP deflator inflation, consistent with the definition in QPM. In QPM, however, expected rather than actual inflation is used. In contrast to ex ante measures of inflation, the ex post measure used in the Taylor-type rules should be less model-specific.
7. Because the deterministic and stochastic simulations are analyzed relative to steady state, the actual level of the equilibrium interest rate is not important for this analysis. In other words, it is the change from the starting point, not the starting point itself, that is important.
8. CPIXFE inflation is used largely to be consistent with the definition in QPM rule. Questions are sometimes raised about whether it would be better to use a measure that also excludes the effects of exchange rate pass-through (sometimes called "core-core" inflation). Therefore, some experiments were done using definitions of inflation based on core-core measures. These gave inferior results, however, in that increased inflation and output variability were both higher.

For this project, coefficient values for the simple Taylor-type rule are selected by examining model properties in response to certain specific shocks and examining average model properties across stochastic simulations.[9] Four criteria, in particular, are important:

i) Avoiding excessive secondary cycling, with “excessive” defined as anything where, following a deterministic shock, the secondary cycle in variables, such as output, interest rates, and inflation, is greater than the primary cycle.

ii) Avoiding monetary policy overreaction to shocks, with “overreaction” defined as a policy response that completely reverses the initial effect of a shock on inflation. (For example, a negative shock to demand should not appear to be an inflationary shock.)

iii) Matching certain properties of the base-case IFB reaction function. This criterion differs from criteria used in the literature. QPM and the base-case IFB rule were developed to provide advice for monetary policy and to incorporate the trade-off of preferences of the monetary authority against the constraints of policy implementation. A policy reaction function that “works well” in a model of the Canadian economy should incorporate similar properties. Therefore, this Taylor-type rule has been developed to try to match preferences such as the time-horizon within which inflation returns to target following a shock, the initial policy response, and the speed with which inflation achieves its new target in response to a reduction in the inflation target (i.e., a disinflation shock).

iv) Comparing average variabilities of inflation, output, and interest rates using stochastic simulations. The coefficients in the rule are chosen based initially on the deterministic simulations; however, the results of the stochastic simulations support these choices. The rules considered in this paper are not “optimal” in the sense of minimizing the variability of inflation and output. Given the size and scope of the model, it is not possible to calculate the “optimal” reaction function. Furthermore, the “optimal” reaction function would not explicitly consider uncertainty or the constraints of policy implementation described above.

## 4.1 The output gap coefficient

There are two main reasons for including the output gap in a Taylor-type rule: the output gap is an indicator of future inflation, and it helps the rule to distinguish between demand shocks and price-level shocks. In a demand shock, the output gap and inflation move in a consistent manner. In a negative demand shock, for example, the economy will move into excess supply, putting

9. Stochastic simulations are simulations in which new shocks are introduced in each period.

downward pressure on inflation. The monetary authority has every reason to offset such a shock with a decline in interest rates. In a price-level shock, however, it is the monetary response to the shock that opens up an output gap. In such a shock, the monetary authority faces a trade-off between inflation and output variability. A monetary authority who wishes to minimize both of these variabilities, therefore, may want to react less aggressively in a price-level shock.

Figures 1 to 3 show the effects of increasing the weight on the output gap in three deterministic shocks: a temporary, negative demand shock; a disinflation shock, where the monetary authority lowers the inflation target; and a temporary appreciation of the exchange rate. For both the demand and exchange rate shocks, as the weight on the output gap increases, so does the aggressiveness of the monetary response to try to offset the effects of the shock. For the disinflation shock, as the weight on the output gap increases, the initial interest rate response is smaller, since the economy goes into excess supply.

As the weight on the output gap increases, the degree of secondary cycling in inflation and interest rates increases. This is most severe in the demand shock. Too high a weight on the output gap causes such a large interest rate response to a negative demand shock that an increase in inflation emerges without any evidence of inflation falling below the midpoint of the target range. On the basis of the criteria described above, particularly to ensure that a negative demand shock does not turn into an inflationary shock and to limit the degree of secondary cycling, a coefficient value of 0.5 was chosen for the output gap.[10]

This analysis does not take into account concerns about uncertainty over the measurement of the output gap. A number of studies (for example, Smets 1998) have concluded that, as this uncertainty increases, the optimal weight on the output gap term decreases. Srour (1999) finds that if the estimation errors are white noise, the optimal weight is unchanged, but if the errors are serially correlated, the optimal weight will decline. Of course, the 0.5 weight chosen is also not in any sense “optimal.” In fact, the stochastic simulation results suggest that the optimal weight that minimizes deviations in output and inflation would be higher. It is not obvious, therefore, to what extent considerations of uncertainty would reduce this coefficient value.

## 4.2 The inflation gap coefficient

The inflation gap coefficient affects the aggressiveness of response to all shocks in a similar manner. In particular, it affects the speed with which inflation returns to target and the degree of

10. While the coefficient on the inflation gap is 2 in the graphs shown, the conclusions regarding the effects of increasing the weight on the output gap are robust across different weights on the inflation gap.

secondary cycling. A number of inflation gap coefficients were examined. Figures 4 to 6 show the results of simulations. It was found that weights of 0.5 and 1.0 can be eliminated on the basis that they do not bring inflation back to target quickly enough. Similarly, weights in excess of 2.5 can be eliminated, since they induce too much cycling in all variables. With a weight of 5, the cycling seems not to dampen over time and borders on instability. On this basis, therefore, a weight of between 1.5 and 2.5 seems to be appropriate, and the midpoint of 2 was selected.[11]

### 4.3 Stochastic simulations of Taylor-type rules

Figure 7 shows the results of stochastic simulations of Taylor-type rules with varying weights on the output gap and inflation gap components. The shocks are calibrated to be generally representative of the historical distribution of shocks.[12] (The appendix gives further details on the shock calibration.) The top graph in Figure 7 shows the results in terms of average inflation variability and average output variability. The bottom graph shows the results in terms of inflation and interest rate variability. Each line in the graphs shows rules with a given weight on the output gap component. Moving along a line shows the effects of changing the weight on the inflation gap component. Also marked on each graph is the base-case IFB rule for QPM.

As the weight on the output gap component is increased, output variability falls, with little change in inflation and interest rate variability. As the weight on the inflation gap is increased, inflation variability falls initially, but output and interest rate variability increase. Furthermore, as the weight on the inflation term gets higher, the trade-off becomes more unfavourable. For weights greater than 3, inflation variability begins to increase again. The coefficients selected above—a coefficient of 2.0 on the inflation gap, together with a coefficient of 0.5 on the output gap—appear to be reasonable, based on the stochastic simulations. In particular, a weight on the inflation gap of 2.0 is below the point at which inflation variability starts to increase.

The Taylor-type rules are generally associated with higher levels of inflation, output, and interest rate variability than the base-case QPM rule. Many studies have found that Taylor-type rules perform well compared to optimal model rules, so it is not fully understood why Taylor-type rules perform poorly in QPM. A major difference between the Taylor rule and the base-case rule is that the base-case rule is explicitly forward-looking. While the Taylor rule exploits the predictive power of past inflation and output for future inflation, it does not directly capture other expected

11. Similar to the discussion on the inflation gap in section 4.2, this result is not sensitive to the use of 0.5 as the coefficient on the output gap.

12. For the stochastic simulations, each rule was simulated 100 times for a period of 109 quarters; however, the first nine observations were dropped from the analysis. The averages in the graphs represent averages across the replications as well as over time.

exogenous developments, such as fiscal policy and commodity prices. In QPM, if the monetary authority can better anticipate future inflation using more information, then acting pre-emptively prevents shocks from being embedded in expectations. Part of the explanation is also likely owing to the non-linear Phillips curve within QPM.[13]

Another reason why a Taylor-type rule might not work well in small open economies such as Canada's is that it does not take exchange rate movements directly into account. In the shock calibration used for Figure 7, exchange rate variability is somewhat lower than that experienced over history. To try and test the importance of small open-economy effects, the Taylor-type rules shown in Figure 7 were resimulated, this time with a shock calibration that had increased exchange rate variability.[14] The results are shown in Figure 8. All variabilities are higher for both the Taylor-type rules and the base-case rule. It does appear, however, that the Taylor-type rules deteriorate more than the base-case rule. Concerns about open-economy effects have led to interest in open-economy extensions to the simple Taylor rule.

# 5. The Ball Rule

Ball (1999) derives an open-economy extension to the simple Taylor rule. The Ball rule is shown in equation (3):

$$\eta(r_t - r^*) = \alpha \cdot (\Pi c_t - \overline{\Pi c}) + \beta \cdot (y_t - y^*) + (1-\eta)(e_t - e^*) \qquad (3)$$

With the open-economy effects included, the Taylor rule changes in two main ways. First, the inflation gap component is defined in terms of "core-core" inflation $\Pi c_t$; i.e., CPIXFE inflation with direct exchange rate pass-through effects removed.[15] Second, this rule now includes an exchange rate gap $e_t - e^*$, where $e_t$ is the log of the real exchange rate and $e^*$ is its equilibrium value, and where an increase in $e_t$ represents a depreciation. This implies that the rule can be written as an MCI rule, where the policy variable is a combination of the interest rate gap and the

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13. Isard, Laxton, and Eliasson (1999) find that the Taylor rule does not work well in their model with a non-linear Phillips curve.

14. The standard deviation of the quarterly real exchange rate is 4.5 in the first calibration, which is below the historical value. This was necessary to better match historical interest rate variability. In the alternative calibration, this was increased to the historical standard deviation of around 6.9. For more details on calibrating the shocks for stochastic simulations, see the appendix.

15. The core-core price level was derived from QPM by subtracting a weighted average of 10 lags of the log of the real exchange rate from the log of prices (excluding food and energy): $lcpi_{core\text{-}core} = lcpi_{xfe} - (0.0182*e_t+0.0255*e_{t-2}+0.032*e_{t-3}+0.0186*e_{t-4}+0.0144*e_{t-5}+0.0104*e_{t-6}+0.007*e_{t-7}+0.0048*e_{t-8}+0.0031*e_{t-9}+0.0015*e_{t-10})$. Ball uses a simpler definition with only one lag; however, this does not work well in QPM.

exchange rate gap. For these simulations, the equilibrium real exchange rate is a constant. Therefore, shocks to $e_t - e^*$ represent portfolio shocks to investors and not shocks to the fundamentals of the exchange rate.

Ball derived the weight on the exchange rate to be equal to or slightly greater than this variable's relative effect on expenditure. For Canada, this is approximately 0.3.[16] The weights for the inflation and output gaps were based on those selected for the simple Taylor-type rule, but scaled to take account of the extra term.[17]

The temporary exchange rate shock is a good example of a shock that the Ball rule would be expected to handle better than the Taylor-type rule. As Figure 9 shows, interest rates coming from the Ball rule respond more quickly to the shock, and, as a result of moving early, the Ball rule gives a smoother policy response than the simple Taylor-type rule, with a slightly smaller trough in interest rates. Both interest rate and inflation variability are reduced. Clearly, by acting in a more pre-emptive fashion, the Ball rule is able to handle temporary exchange rate shocks more efficiently.

The Ball rule was simulated in the stochastic environment with the two shock calibrations used for the Taylor-type rule simulations. As before, different values were used for the coefficients on the output and inflation gaps. The exchange rate gap coefficient was held constant at 0.3. Figures 10 and 11 show the results. The measure of inflation variability in these graphs is still defined in terms of CPIXFE inflation, even though the Ball rule uses an inflation gap defined in terms of core-core inflation. The results from the Ball rule are shown in dark lines. The previous results from the Taylor-type rules are shown in shaded lines, to aid comparison.

With the calibration based on historical interest rate volatility, there is very little difference between the Ball rule and the Taylor rules, although the Ball rule results in slightly higher output variability. With the calibration based on higher exchange rate variability, however, the Ball rule gives lower output and interest rate variability. In both the top and bottom graphs of Figure 11, the lines for the Ball rule generally shift to the left. There are no gains in terms of inflation variability. For higher values on the inflation coefficient, the Ball rule gives higher inflation variability than the simple Taylor rules. These results suggest that the decision of whether to use a Ball rule will depend on the degree of expected exchange rate variability.

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16. Deterministic simulations were also run, varying the weight on the exchange rate term. Based on these simulations, a coefficient value of 0.3 appears to be appropriate.
17. If we assume that $e = -\theta r$, the Ball rule can be written as: $\eta(r_t - r^*) = \alpha \cdot (\Pi c_t - \overline{\Pi c}) + \beta \cdot (y_t - y^*) + (1 - \eta) \cdot \theta \cdot (r_t - r^*)$. Substituting in for the exchange rate and rewriting the rule in terms of the interest rate gives the Ball coefficients as the comparable Taylor coefficients multiplied by $(\eta - (1 - \eta)\theta)$. As in the case of Ball, $\theta$ is assumed to be around 2.

When the Ball rule is considered as a policy alternative, some practical problems arise in defining the equilibrium exchange rate. There is substantial uncertainty about how to define this equilibrium, and the results of the rule will be sensitive to different definitions. When shocks are performed with artificial data, it is simple to define the equilibrium exchange rate as a constant. However, it is much harder to measure when historical data are used, since the equilibrium exchange rate is likely to have varied in the past. As stated above, work by Smets (1998) suggests that as uncertainty about a variable increases, the relative weight placed on it in a monetary rule should decline. Uncertainty about the exchange rate gap is at least as large as uncertainty about an output gap term, so taking this into account would presumably lead to a lower weight. This will be discussed further in section 7.

A final concern with the Ball rule is that it may not perform well in situations where there are trend movements in the equilibrium exchange rate. In the deterministic and stochastic experiments, all the exchange rate variability is in terms of the actual exchange rate. The equilibrium exchange rate is kept constant. This may not be the case, however, over history. The equilibrium exchange rate has likely shown periods of trend increase and decrease, reflecting such factors as trends in commodity prices and government debt. In this situation, if the actual exchange rate lags behind the equilibrium, the exchange rate gap will have the wrong sign. For example, if the equilibrium and actual exchange rates are both appreciating, but the actual is above (i.e., depreciated compared to) the equilibrium exchange rate, the exchange rate gap term will be positive. This will put upward pressure on interest rates in the Ball rule, at the same time as the appreciating exchange rate is placing downward pressure on inflation. The result of using the Ball rule in such an environment is a considerable fall in CPIXFE inflation. As section 6 will show, historical data suggest that this is a valid concern.

## 6. The Change Rule

Another form of open-economy rule that is sometimes used (for example, Dillén et al. 1999) is very similar to the Ball rule, but includes the change in the exchange rate rather than an exchange rate gap term. The Change rule can be written as:

$$\eta(r_t - r^*) = \alpha \cdot (\Pi c_t - \overline{\Pi c}) + \beta \cdot (y_t - y^*) + (1 - \eta) \cdot (e_t - e_{t-1}) . \tag{4}$$

This rule is harder to justify on theoretical grounds, since it is not derived from a model. The monetary authority in this case still uses an inflation gap based on core-core inflation, but nevertheless adjusts interest rates in response to all exchange rate movements. This rule does have the advantage, however, of not depending on a notion of an equilibrium exchange rate that may be hard to measure.

Figure 12 shows the results of a deterministic exchange rate shock for all three rules. The same coefficients are used in the Change rule as were used in the Ball rule. The deterministic simulations for the Change rule are very similar to those for the Ball rule, although the Change rule performs marginally worse. Figures 13 and 14 provide results in a stochastic environment. As before, the shaded lines show the Taylor rule results. Not surprisingly, there are few significant differences between the Change rule and the other rules simulated with historical interest rate volatility. The Change rule, however, appears to be associated with higher output variability. For the calibration with the higher exchange rate variability, however, the Change rule provides lower output and interest rate variability than the Taylor rules, but not as much of a reduction as with the Ball rule.

Clearly, the question of which rule performs "best" depends greatly on the degree of expected exchange rate variability. If the frequency of temporary shocks to the exchange rate is expected to be high, there are gains in the artificial environment from adopting an open-economy rule. If the frequency of such shocks is not expected to be high, the Taylor rule is preferable. With the Ball rule, however, there are other concerns associated with the difficulties of defining the equilibrium exchange rate.

# 7. Evaluating the Information in Alternative Rules

To further assess the characteristics of different Taylor-type rules, the three selected rules are used to run static counterfactual experiments. Each rule is calculated over history, showing what the real interest rate recommendation coming from the rule would have been at any point in time. An important caveat of this exercise is that future output and inflation do not reflect in any way the interest rate profile coming from the Taylor-type rule. Thus, the exercise does not show how the economy would have evolved if a Taylor-type rule had been followed. It merely shows for any point in time, given the output gap and the inflation gap, how the interest rate proposed by a Taylor-type rule would have differed from what the interest rate actually was.

## 7.1 Static counterfactual experiments with revised data

Figures 15 and 16 show the original Taylor rule and the rule proposed in section 4, calculated over historical data and compared to the historical real commercial paper rate. Values for the equilibrium real interest rate are based on a filter of the historical data, adjusted for a risk premium based on the debt-to-GDP ratio, which converges in the long run to a value close to its historical average.[18] The inflation target is a combination of an H-P filter over the beginning of the sample and the midpoint of the actual announced inflation-control range over the end of the sample. Obviously, as there was no explicit inflation-control range for the beginning of the sample, this may not accurately reflect the objective of monetary policy over this period. The output gap is taken from the May 2000 *Monetary Policy Report* (Bank of Canada 2000).

In Figure 15, it is clear that the original Taylor rule replicates the increases in real rates experienced in the late 1970s. However, in 1981 and in the late 1980s and early 1990s, actual interest rates are considerably higher than suggested by the original Taylor rule. A comparison of Figures 15 and 16 shows the effect of increasing the rule's aggressiveness by raising the coefficient on inflation. The interest rate coming from the proposed rule more closely matches the peaks in rates in both 1980 and in the late 1980s and early 1990s. In late 1991, the interest rate suggested by the proposed Taylor rule falls quite sharply and substantially below actual rates at the time, for two complementary reasons: inflation falls below the target, and the output gap is negative because of the onset of a recession. Therefore, both inflation and the output gap suggest lowering interest rates.[19] Beginning in 1994, the deviations between proposed interest rates and actual rates are smaller.

Figure 17 depicts the interest rate setting by the Taylor, Ball, and Change rules. Similar to the equilibrium interest rate, the measure of the equilibrium real exchange rate is based on a filter of historical data that converges to an estimate of its long-run equilibrium value.[20] The open-economy rules tend to give higher interest rates when the exchange rate is depreciating (e.g., the periods 1977–79 and 1985–86). They are also more volatile, especially during the turning points. The Ball rule tends to be particularly volatile. However, the open-economy rules sometimes differ substantially from each other. For instance, during the 1992–93 period, the two open-economy rules deviate from the Taylor rule in opposite directions. This is because while the exchange rate is depreciating over this time, putting upward pressure on interest rates in the Change rule, there is a negative exchange rate gap (i.e., the exchange rate is stronger than the equilibrium measure), putting downward pressure on the Ball rule. The Change rule comes closer than the Taylor or the Ball rule to characterizing interest rates over this period.

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18. Using a filter has a number of drawbacks. For example, to the extent that policy was too loose in the 1970s, this will bias the estimate of the equilibrium real interest rate down. For research on risk premia, see Fillion (1996). Also, recall that this is an ex post real interest rate calculated using a weighted average of CPIXFE and GDP deflator inflation.
19. Recall that these figures use revised estimates of the output gap over this period.
20. For more discussion regarding estimates of equilibrium exchange rates, see Murray, Zelmer, and Antia (2000).

The static counterfactual highlights some of the difficulties of the Ball rule associated with estimates of the equilibrium exchange rate. Most of the literature that examines the Ball rule uses stochastic simulations relative to a constant equilibrium exchange rate. However, this is a very difficult concept to estimate using historical data. The historical-filter measure used here has many drawbacks. For instance, it implies that the exchange rate always overshoots its equilibrium. An example where the measure may do badly is the 1996–98 period. At that time, the Canadian dollar was depreciating, which would tend to put upward pressure on inflation. However, the filtered measure of equilibrium indicates that the exchange rate was above its long-run equilibrium. Therefore, the Ball rule would recommend lower interest rates than the Taylor rule, which seems to be counterintuitive.

The above counterfactual analysis is not rigorous. Making comparisons with policy settings in the 1970s and 1980s is problematic, since at that time there were no explicit inflation targets and therefore the inflation gap did not play the same kind of role that it does today. Furthermore, definitions and estimates of the equilibrium values have changed dramatically over this period. Kozicki (1999) criticizes the use of Taylor rules on the grounds that they are not robust to changes in estimates of the output gap stemming from data revisions and/or small changes in definition. The fact that real-time data look very different from the final revised series has motivated a rapidly growing literature on the implications of real-time versus revised data.[21] Orphanides (2000), for example, looks at real-time data in the United States and suggests that even if the Federal Reserve had been following a Taylor rule, they would have made similar policy "mistakes," as in the 1970s, if real-time rather than revised data had been used.

## 7.2 Static counterfactual experiments with real-time data

To try to take account of some of these problems, a static counterfactual experiment was run using real-time data from the National Accounts from 1993Q2 to 1999Q4. This is the period over which QPM has been used for policy analysis, and thus consistent series of the necessary real-time data are available. Figure 18 compares the revised and real-time data estimates for the output gap, the real exchange rate gap, and the equilibrium real interest rate. Note that the differences between the revised and real-time data can come both from revisions to the data and changes to the estimates of the equilibrium variable. It is clear that in the case of the exchange rate gap, the real-time estimates are at times very different from the current estimates, particularly in 1996 and 1997,

21. Real-time data series use values known only at that point in time.

when the estimate of the sign of the gap changed.[22] This underlines concerns expressed earlier about the robustness of an exchange rate gap in the Ball rule.

Figure 19 shows the results of calculating the interest rate from the proposed Taylor rule and the two open-economy rules, compared to the actual historical interest rate. Graphs of both real and nominal interest rates are shown. The historical real rate is deflated using revised historical inflation data, whereas the three rule measures are based on real-time measures of inflation. Therefore, the historical real interest rate may differ from the Taylor-type rules because of revisions to inflation.[23] It is helpful, therefore, to also compare nominal rates of interest. These are shown in the lower half of Figure 19. However, the discussion below applies to both graphs.

It is evident that between 1993 and late 1996 the Taylor rule gives very low interest rates, much lower than historical rates. As contemporaneous inflation remained consistently below the midpoint of the target range over this period, it is not surprising that the Taylor rule recommends such low interest rates. Also, the positive weight on the output gap (which was in considerable excess supply) in the Taylor rule would put downward pressure on interest rates.

In the second half of 1996 and the beginning of 1997, the interest rates coming from the Taylor rule are more similar to the historical path. For 1997 and 1998, however, they drop substantially below actual rates again. This was a time when actual inflation was beginning to increase and the output gap was still negative but shrinking quickly. This suggests that actual policy was more forward-looking regarding future increases in inflation than the Taylor rule. Another important reason relates to developments in the exchange rate over this period.

The open-economy rules generally give an interest rate profile that is much more similar to actual rates than the Taylor rule, especially over the 1993–95 and 1998 periods. In particular, the Ball rule recommends interest rates above the Taylor rule for the entire sample period. This is largely because the real-time exchange rate gap was strongly positive (so that the actual exchange rate was depreciated relative to its long-run equilibrium value) throughout this period. The Change rule gives an interest rate profile that is more similar to the Taylor rule, but with generally higher interest rates over the last two years because of a depreciating exchange rate. Thus, even though the rule defines the inflation gap in terms of core-core inflation, the exchange rate term in the equation leads the Change rule to give greater weight to exchange rate movements than does the

22. This is striking, as data on the actual nominal exchange rate are not revised. Therefore, all changes come from revisions to inflation differentials and the estimate of the equilibrium real exchange rate.

23. Although CPI data are revised only following a change in the basket, the GDP deflator is subject to more frequent revisions.

Taylor rule. Consistent with previous results, the interest rate path coming from the Change rule is more volatile than that of the Taylor rule.

Over the period examined in these graphs, there have been instances in which interest rates seem to have been changed mainly because of concerns about maintaining orderly financial markets. One example of this is in August 1998, during the Russian debt crisis. None of these rules takes such factors into account.

Clearly, there are considerable limitations to this kind of static counterfactual comparison. As stressed above, they do not show how the economy would have evolved had different rules been followed, but merely what the interest rates coming from the different rules would have been had policy begun following these rules at any given time. However, these experiments do help demonstrate issues that arise when rules are used with historical data.

# 8. Conclusion

By using very general criteria, we have selected coefficients for a simple Taylor rule and two open-economy extensions. Comparing the model properties of these rules in artificial simulations suggests that the extent to which the open-economy rules perform better in terms of reducing output, interest rate, and inflation variability depends on the degree of exchange rate variability. Stochastic simulations that incorporate exchange rate variability comparable to that over history (i.e., the second calibration with higher volatility) show gains from adopting open-economy rules. There are some concerns, however, with the practical application of the open-economy rules. Using the Ball rule raises the problem of defining the equilibrium exchange rate, and of finding a robust rule across slightly different definitions of the equilibrium. Comparisons of real-time and revised series for the exchange rate gap, for example, suggest this is an area of considerable uncertainty. The Ball rule also seems to perform poorly in an environment where there is a trend in the equilibrium exchange rate. The Change rule, while not using the equilibrium exchange rate, is less justifiable on theoretical grounds and tends to be associated with more volatile interest rate changes than the Taylor rule.

None of the Taylor-type rules considered does as well as the IFB rule in QPM, in part because they do not incorporate future values and therefore are not as explicitly forward-looking as the IFB rule. Clearly, however, the next step is to test the robustness of these proposed rules across a range of other models of the Canadian economy. Additional work on the implications of data revisions and uncertainty about the output and equilibrium gaps would further our understanding of the robustness of Taylor-type rules.

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**FIGURE 1: Comparing Output Gap Coefficients**

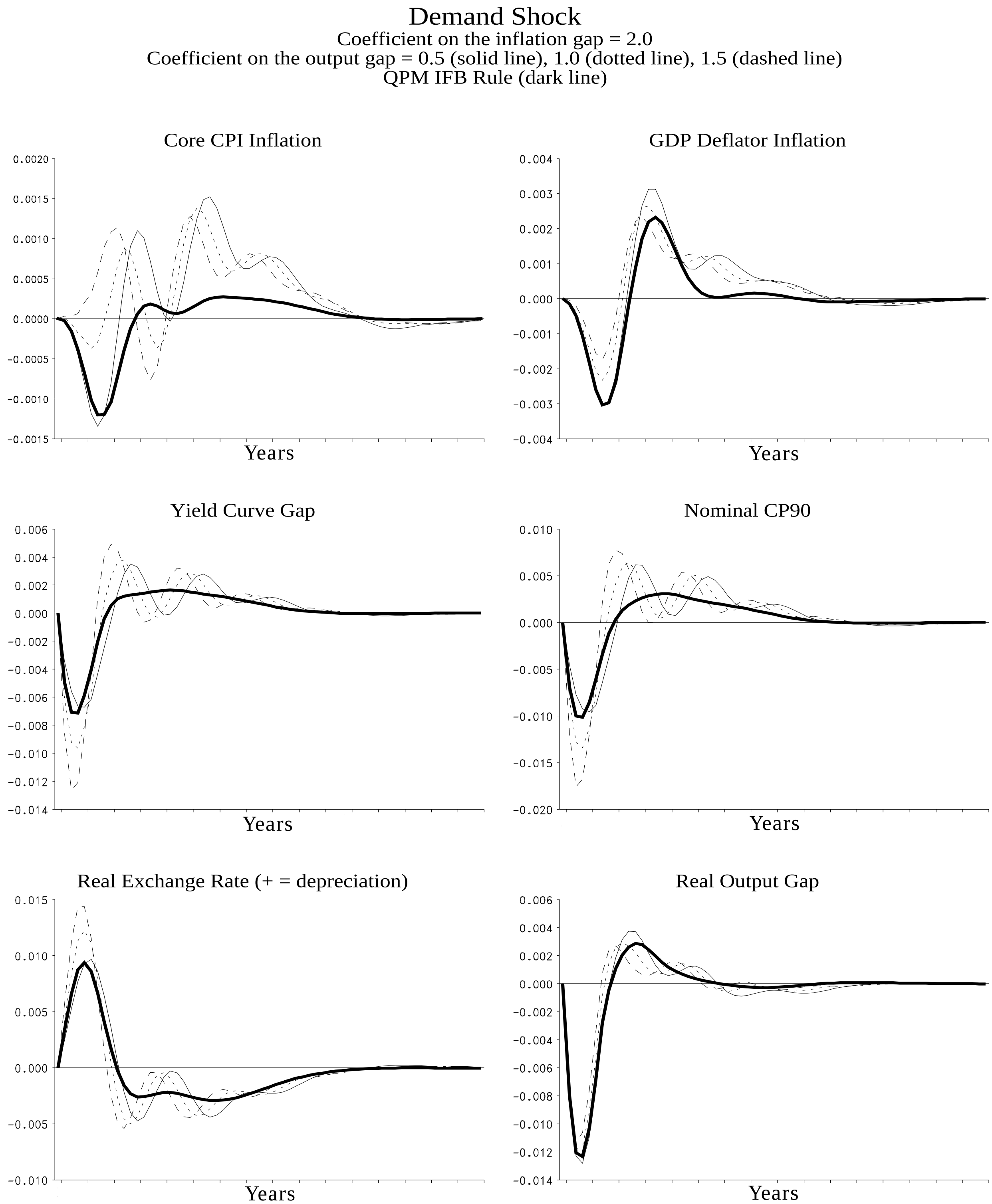


**FIGURE 2: Comparing Output Gap Coefficients**

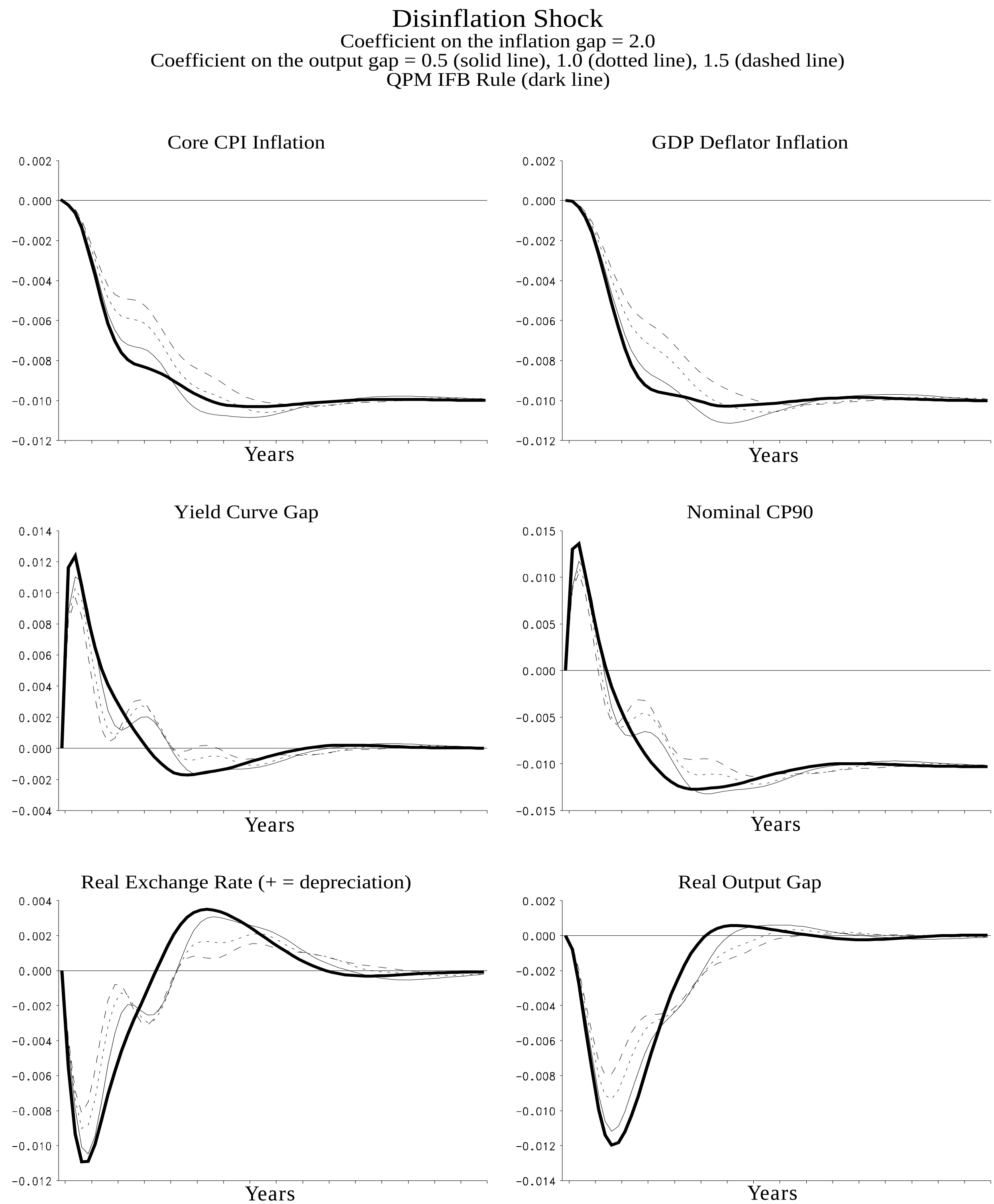


**FIGURE 3: Comparing Output Gap Coefficients**

Exchange Rate Shock
Coefficient on the inflation gap = 2.0
Coefficient on the output gap = 0.5 (solid line), 1.0 (dotted line), 1.5 (dashed line)
QPM IFB Rule (dark line)

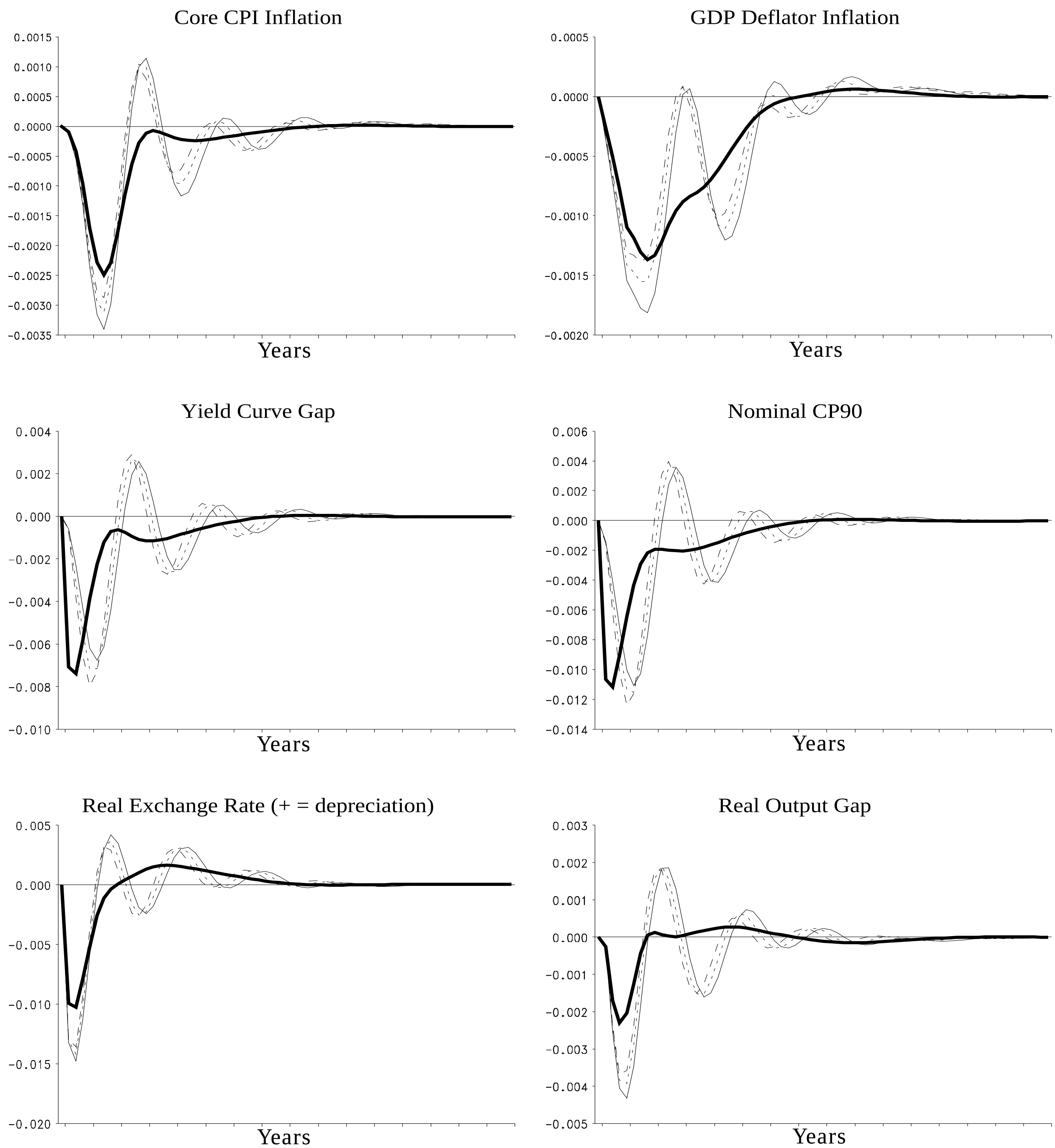


**FIGURE 4: Comparing Inflation Gap Coefficients**

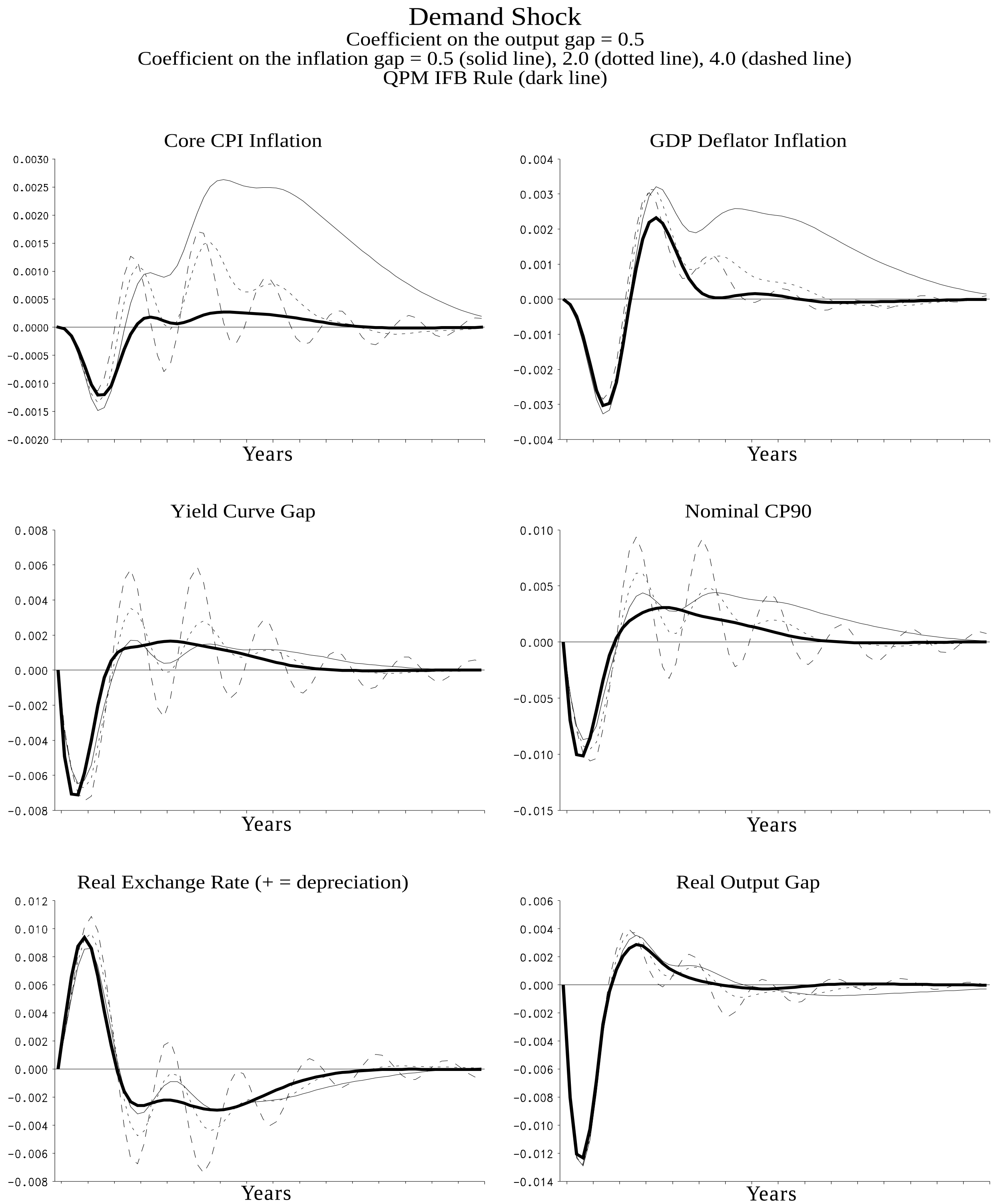


**FIGURE 5: Comparing Inflation Gap Coefficients**

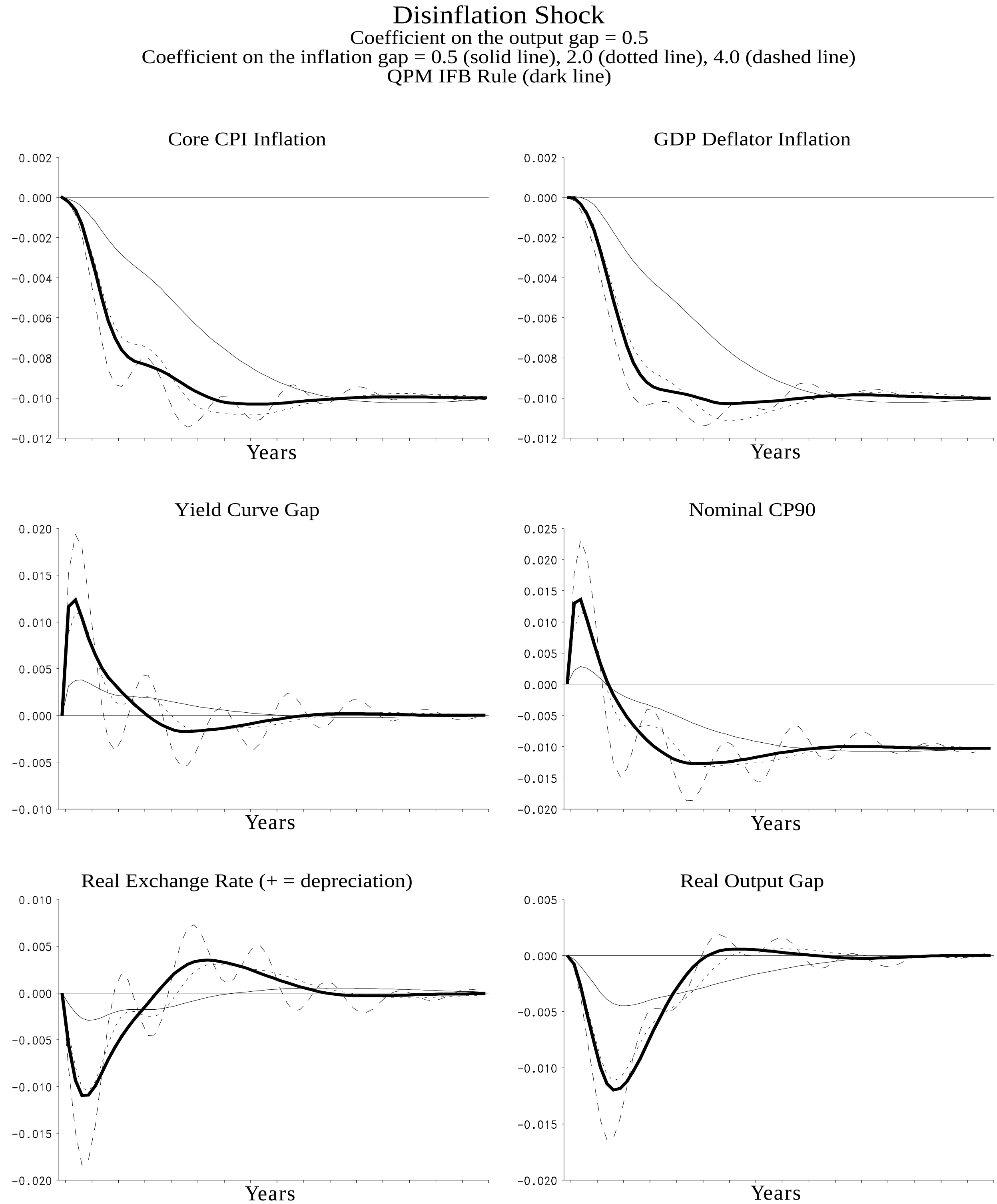


**FIGURE 6: Comparing Inflation Gap Coefficients**

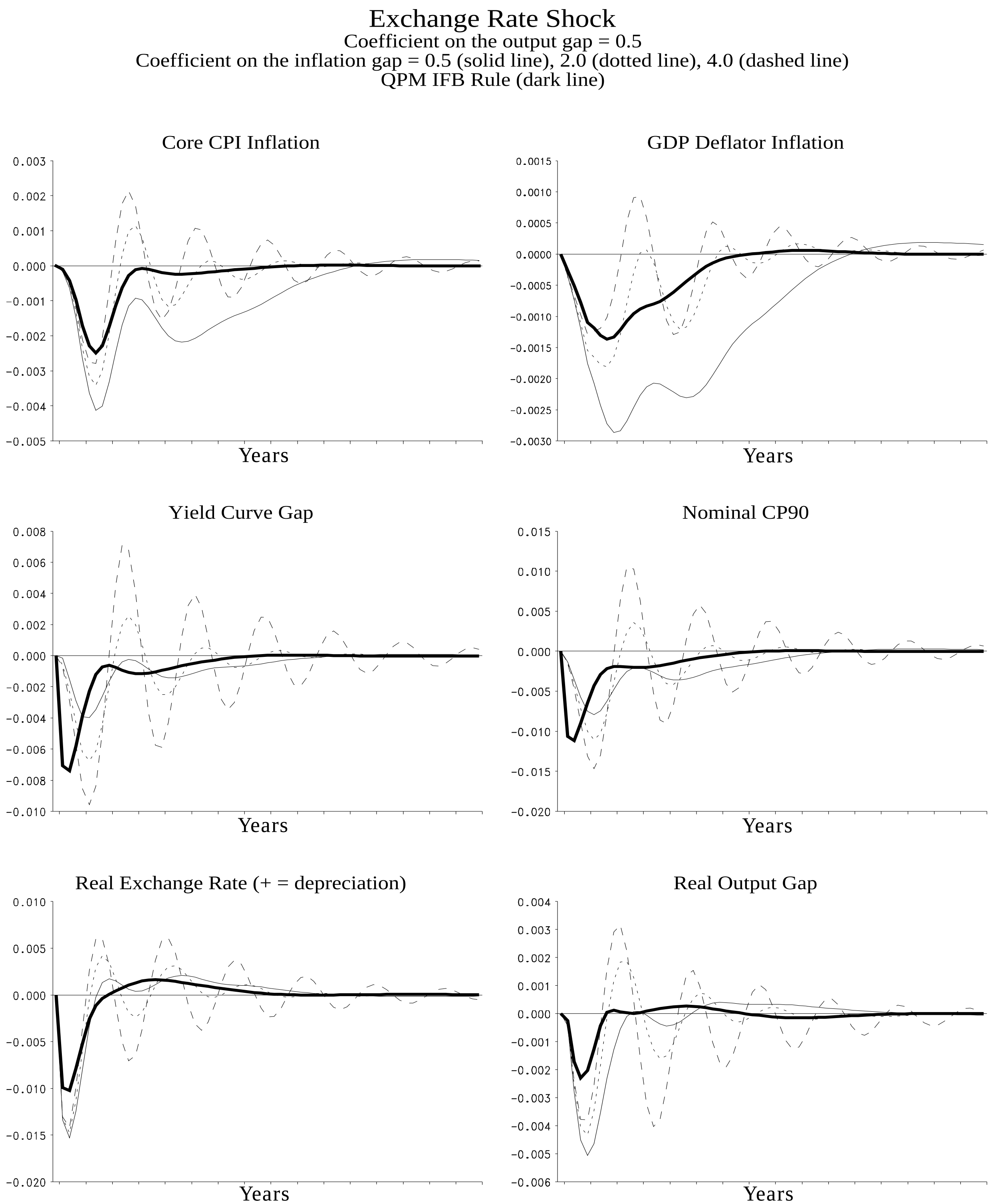
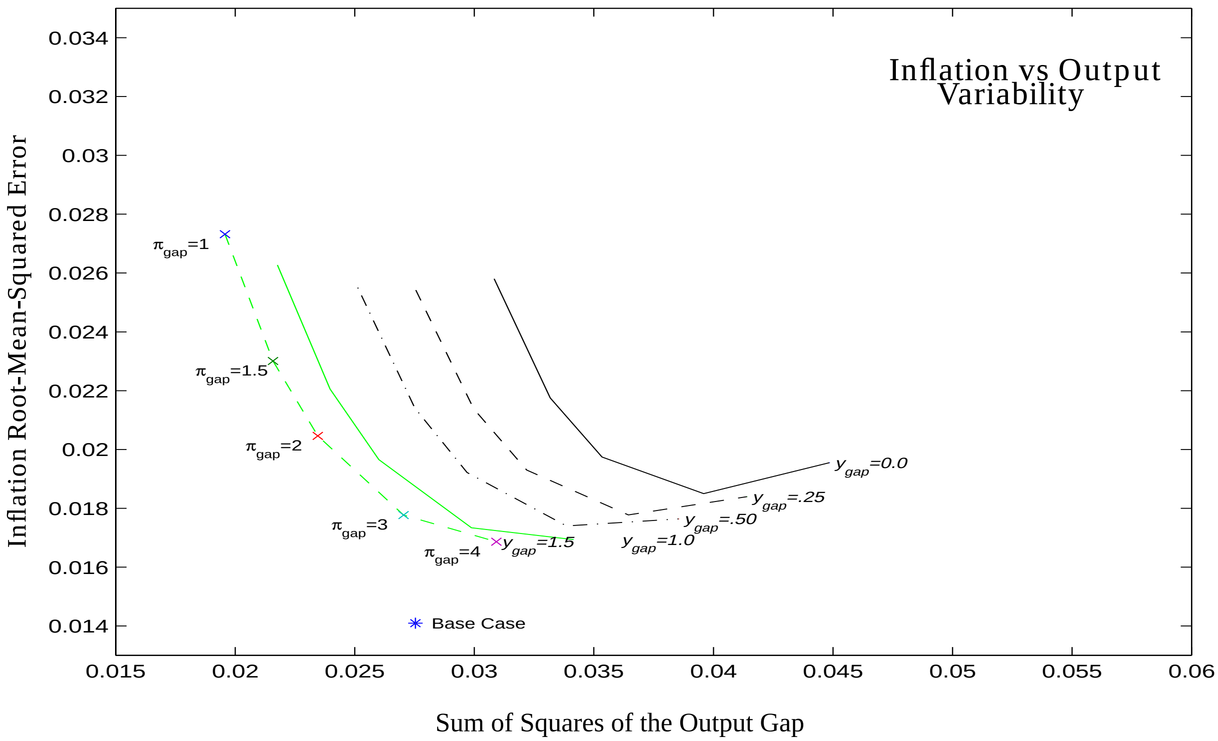


**FIGURE 7: Taylor Rules with Historical Interest Rate Variability**



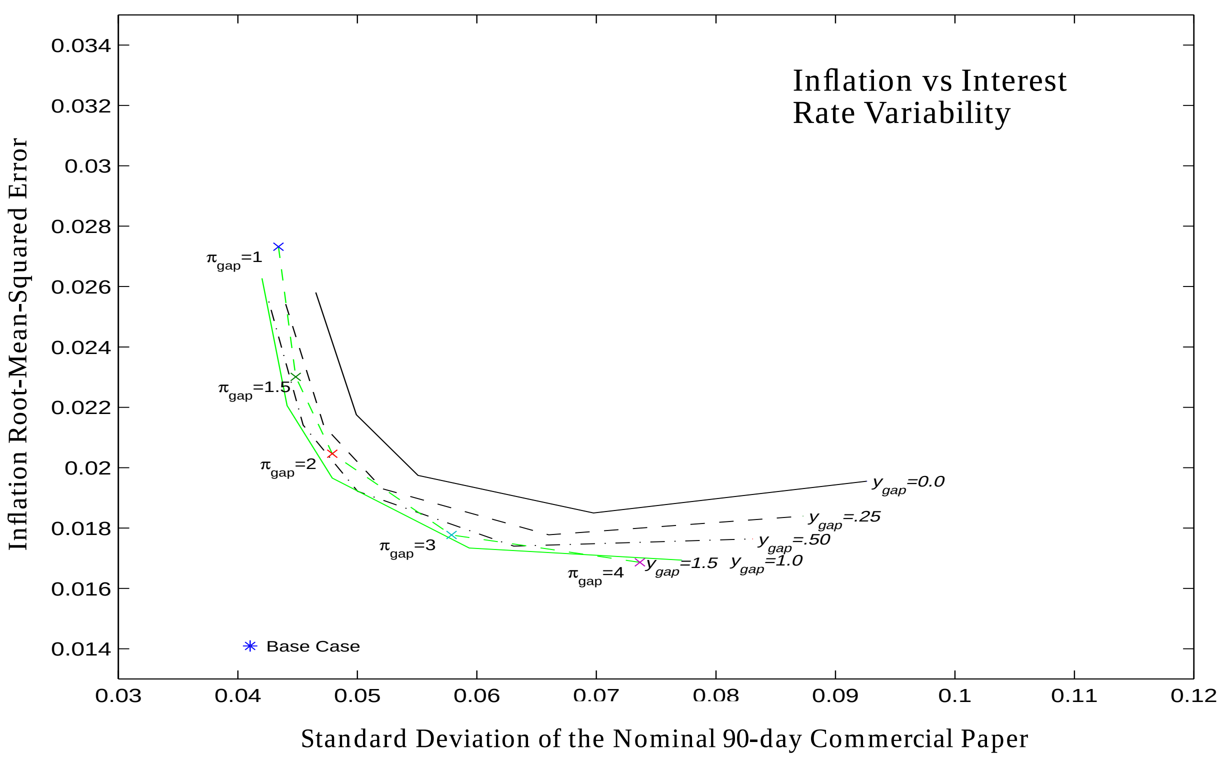
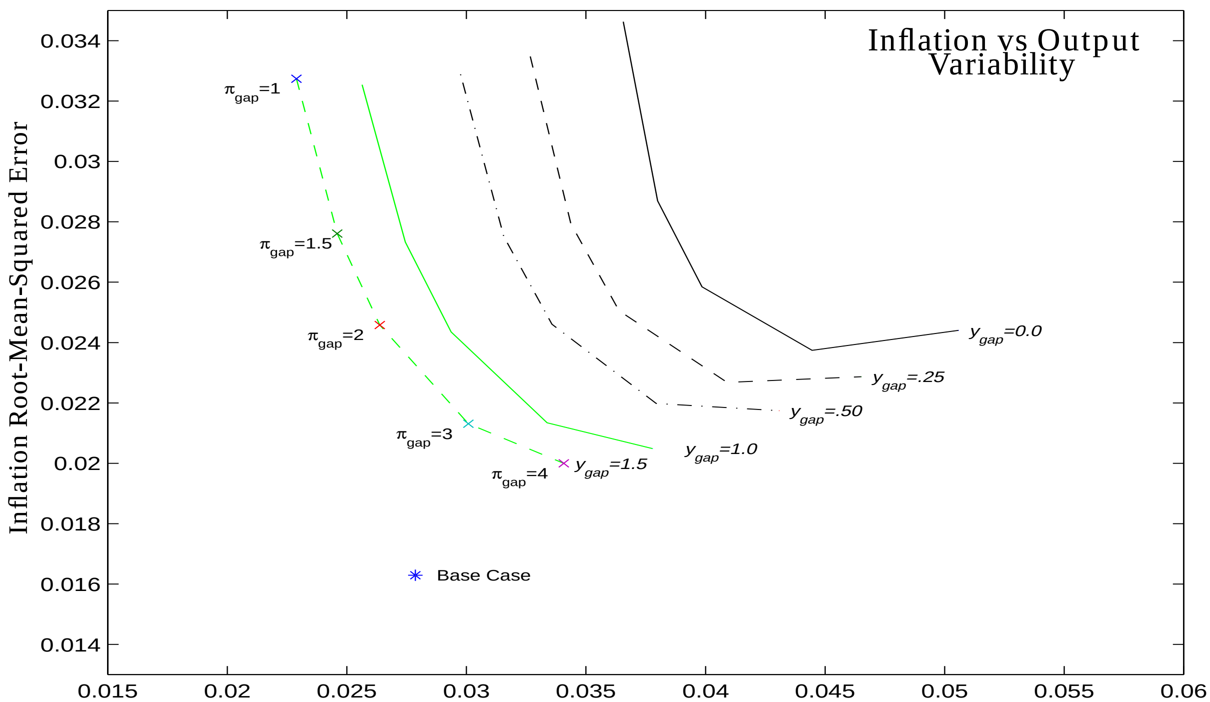



**FIGURE 8: Taylor Rules with Greater Exchange Rate Variability**



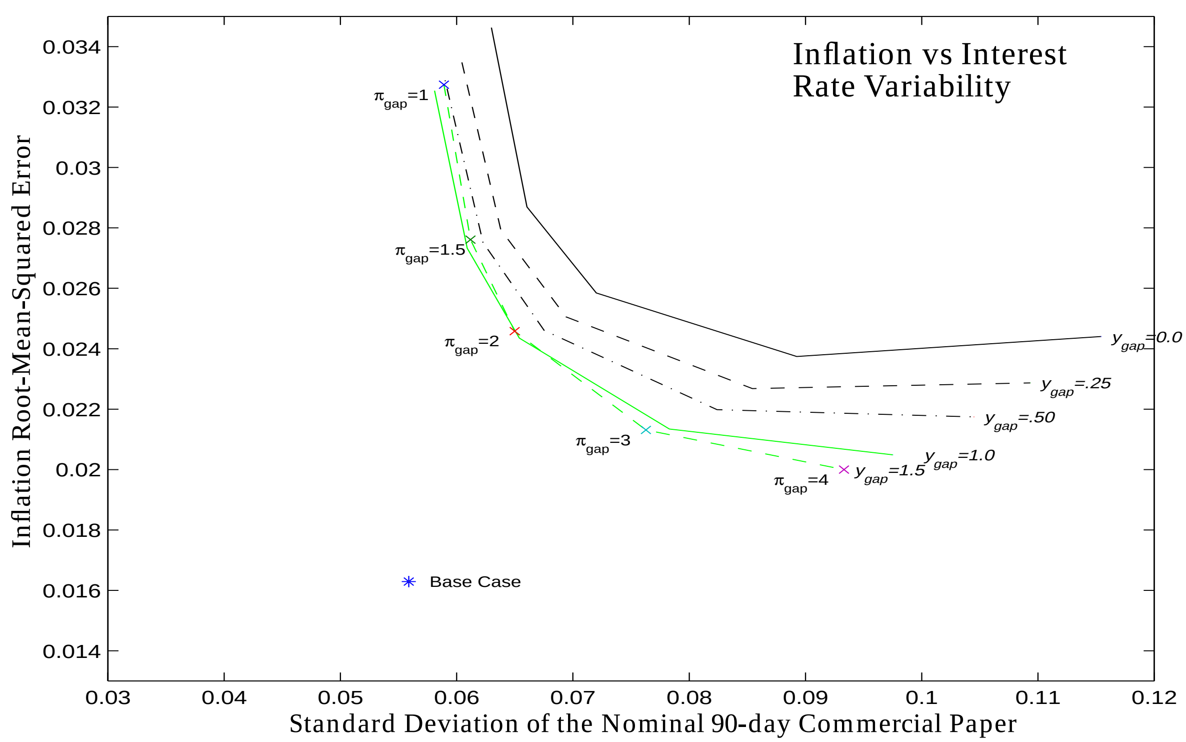



**FIGURE 9: The Ball versus the Taylor Rule**

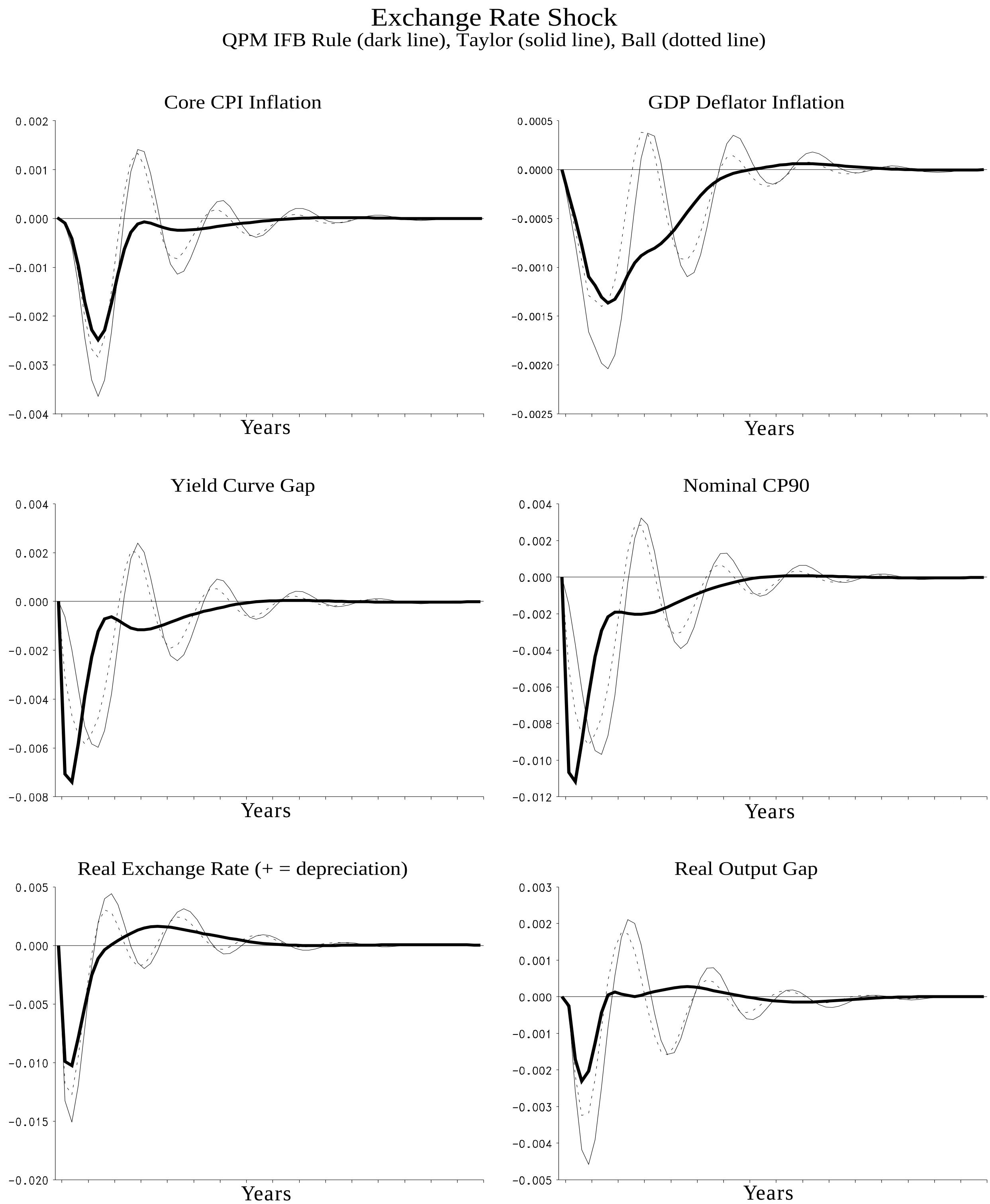
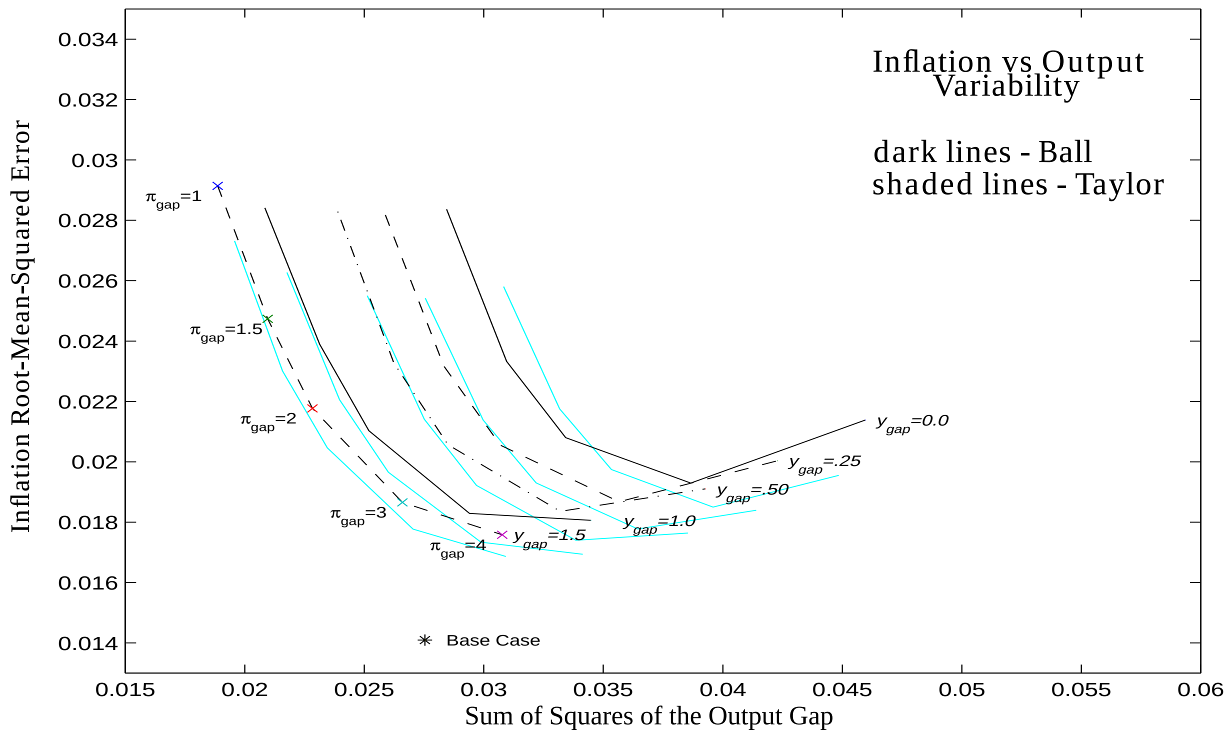


**FIGURE 10: Ball Rule with Historical Interest Rate Variability**



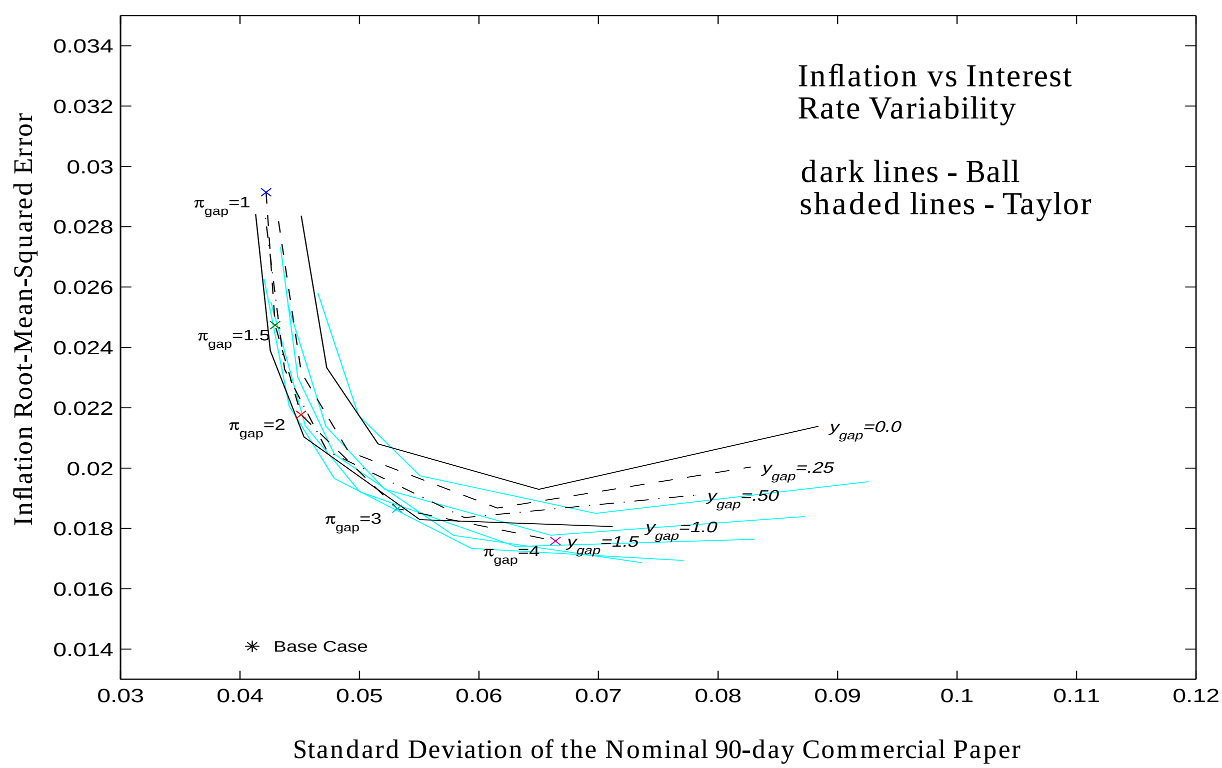



**FIGURE 11: Ball Rule with Greater Exchange Rate Variability**

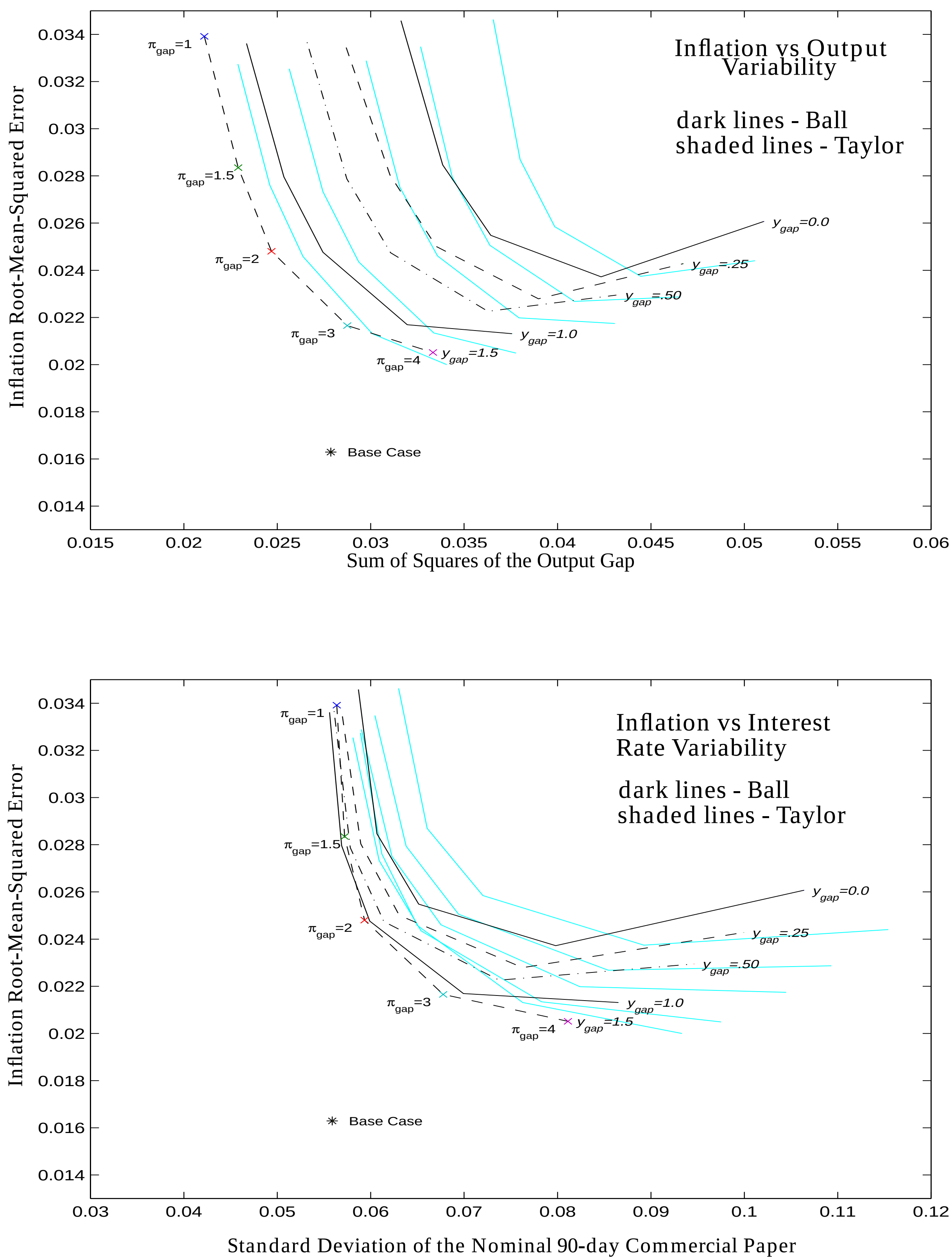


**FIGURE 12: The Taylor, Ball, and Change Rules**

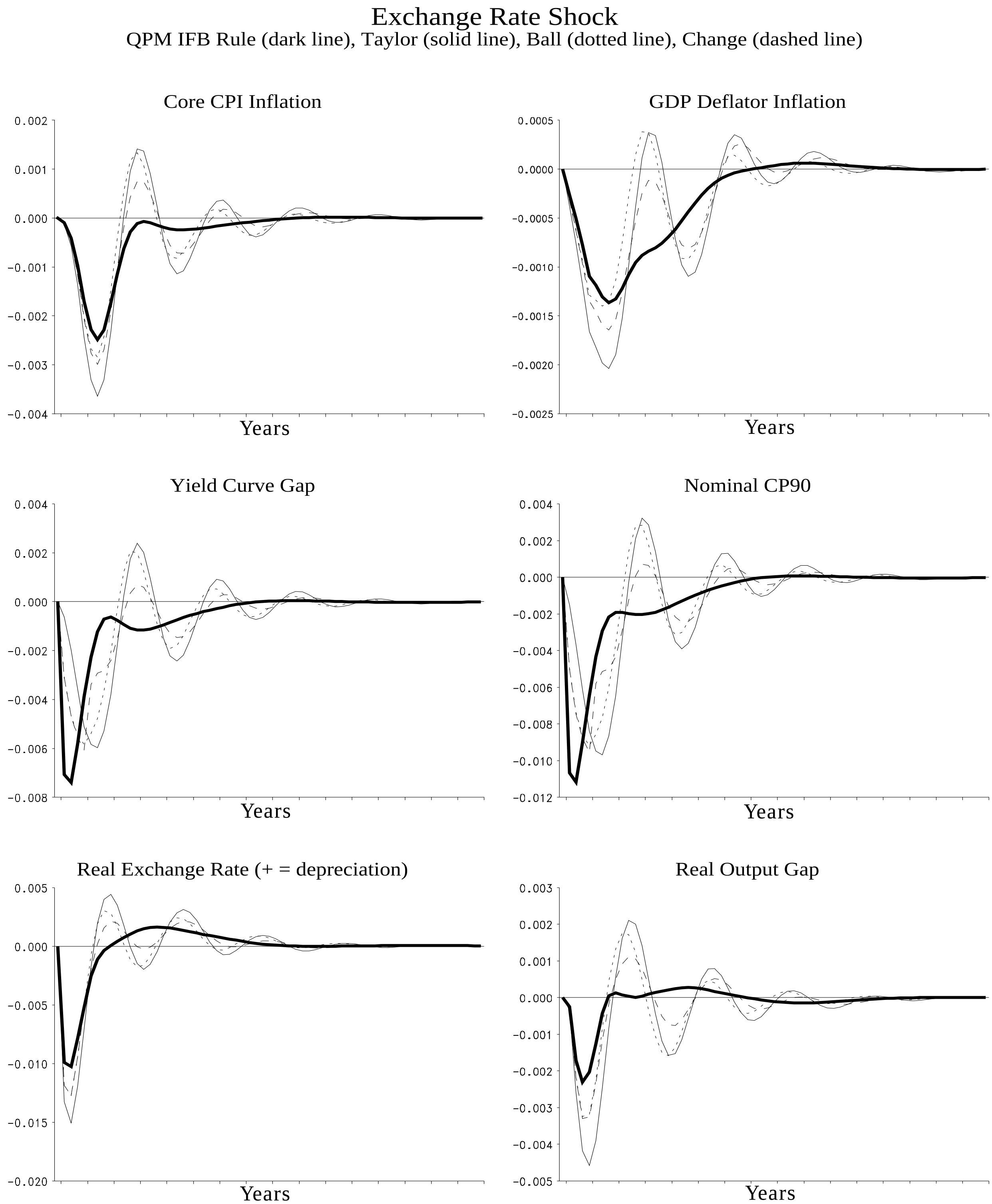
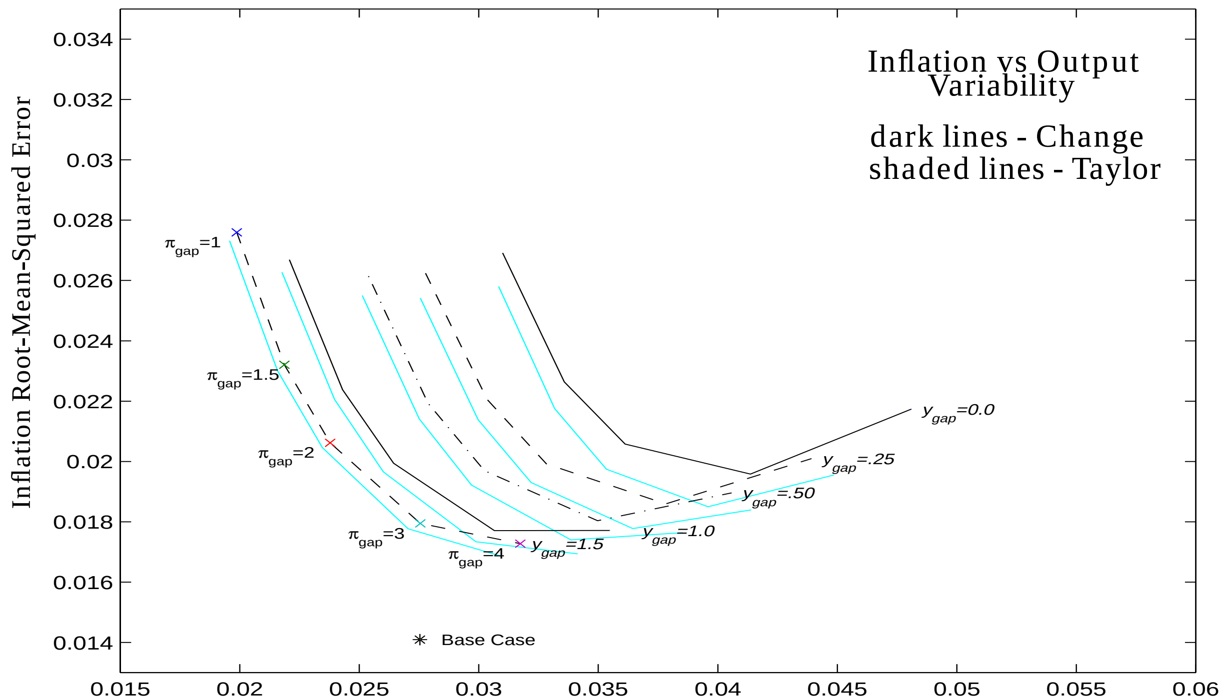


**FIGURE 13: Change Rule with Historical Interest Rate Variability**



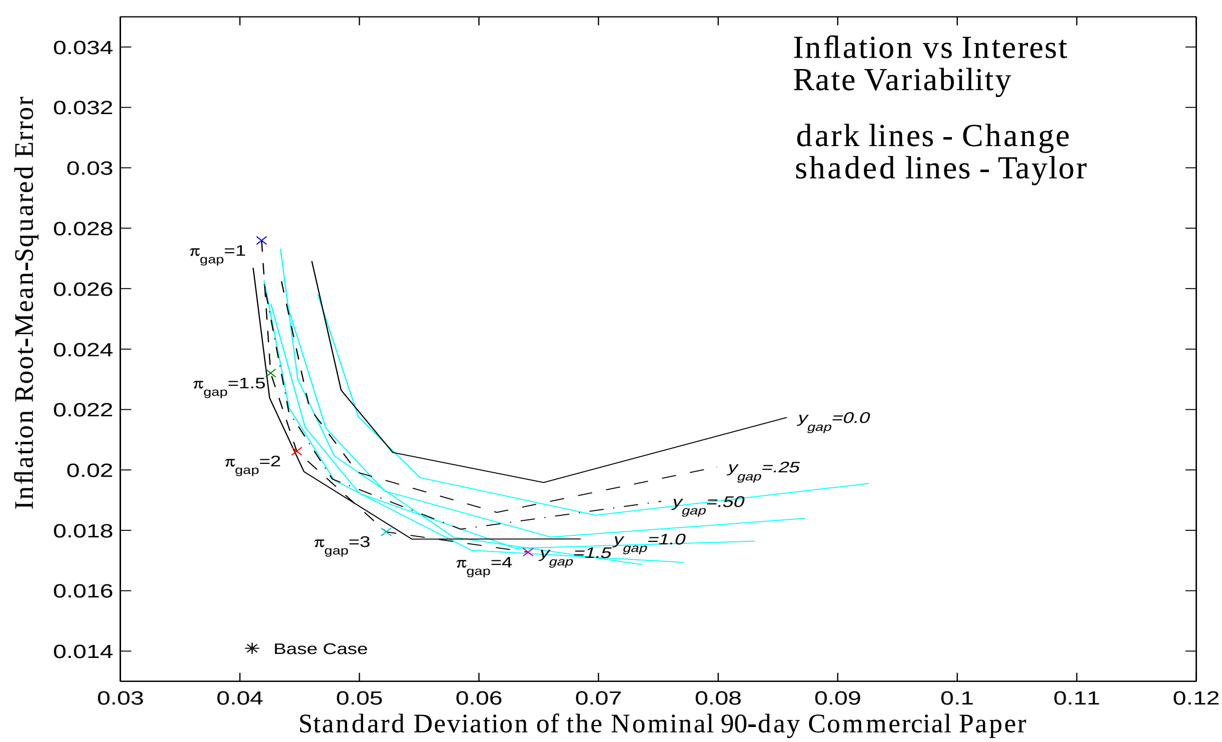
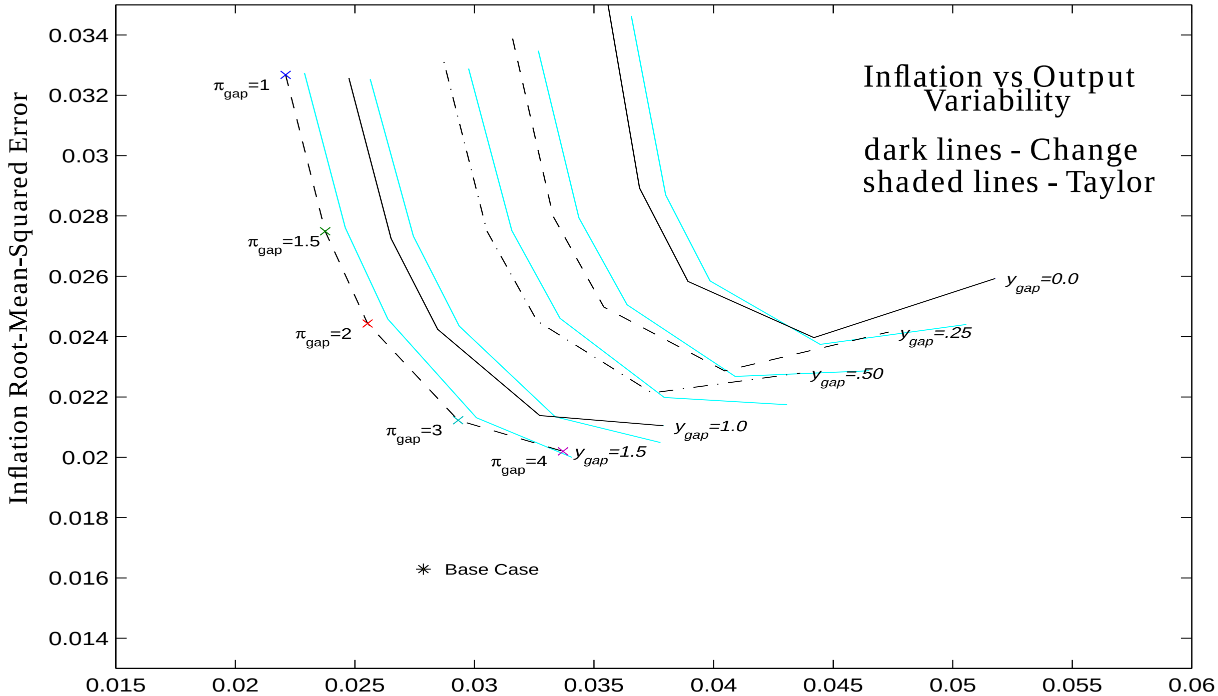



**FIGURE 14: Change Rule with Greater Exchange Rate Variability**



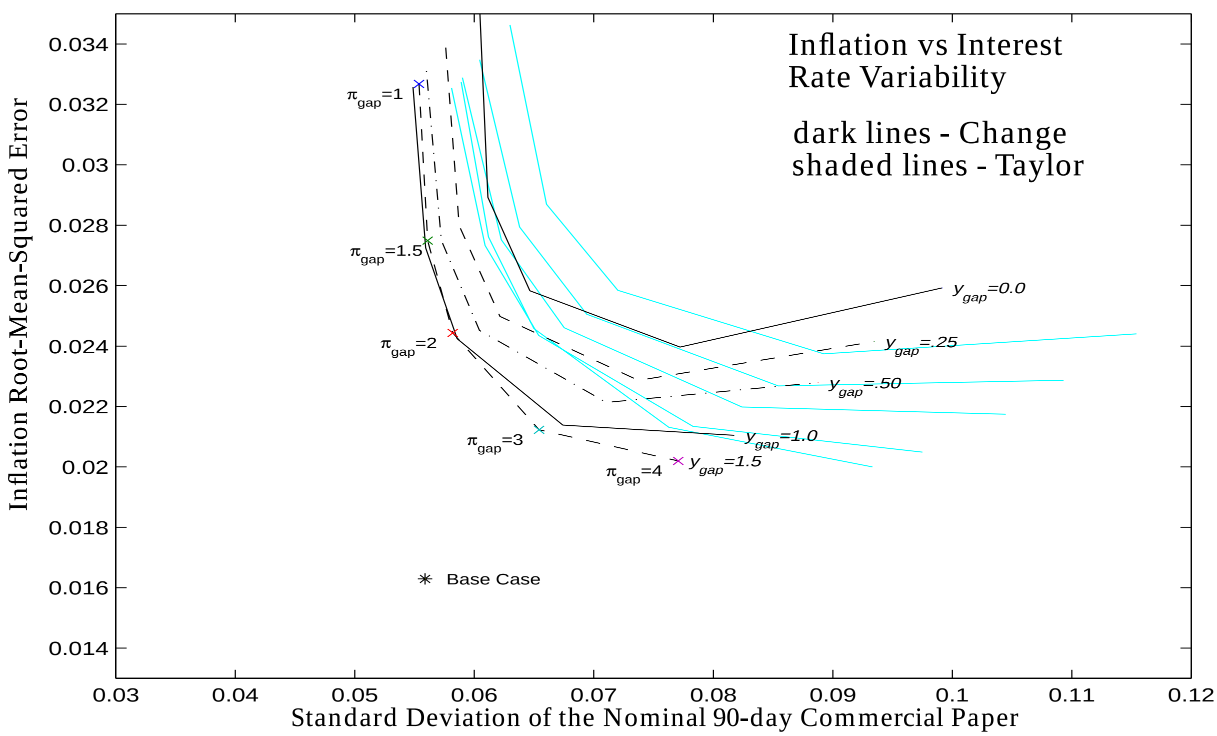



**FIGURE 15: Static Counterfactual Comparing the Original Taylor Rule to the Historic Values for Canada**

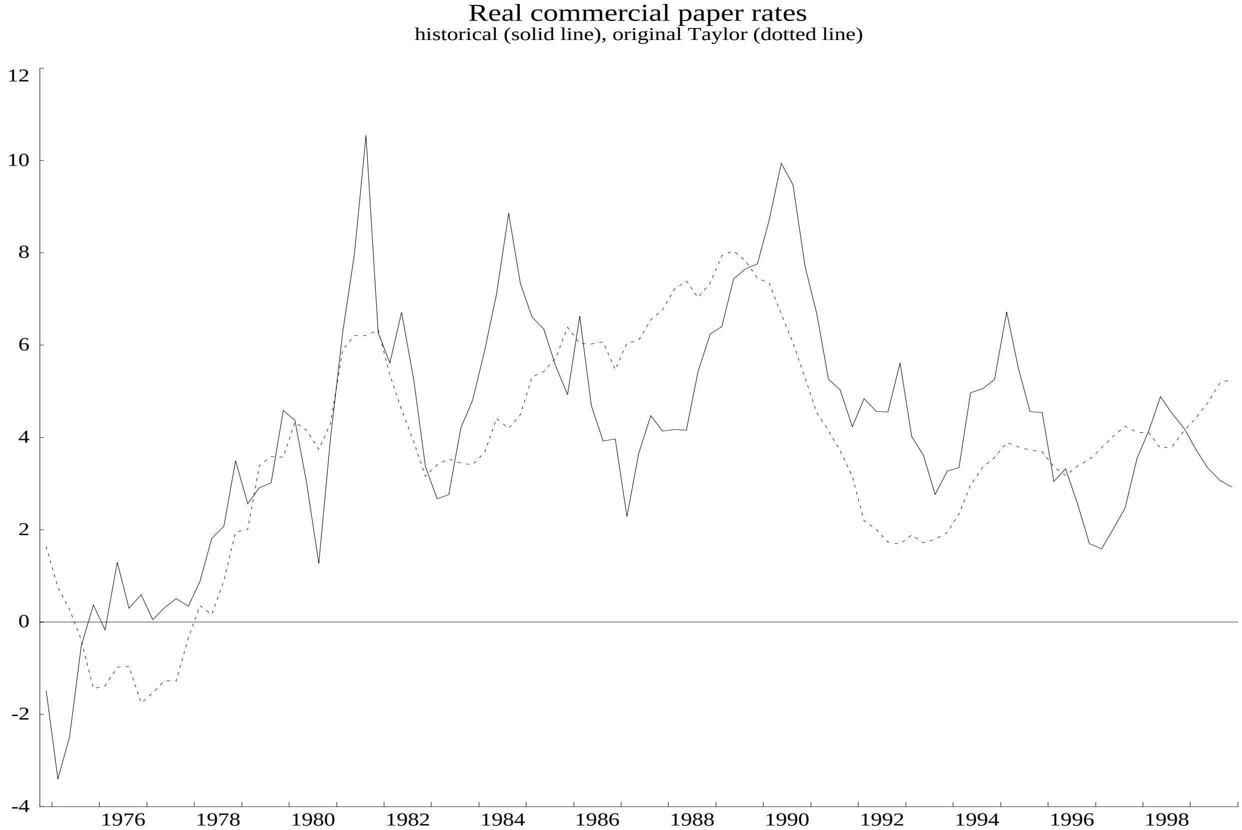


**FIGURE 16: Static Counterfactual using the Proposed Taylor Rule**

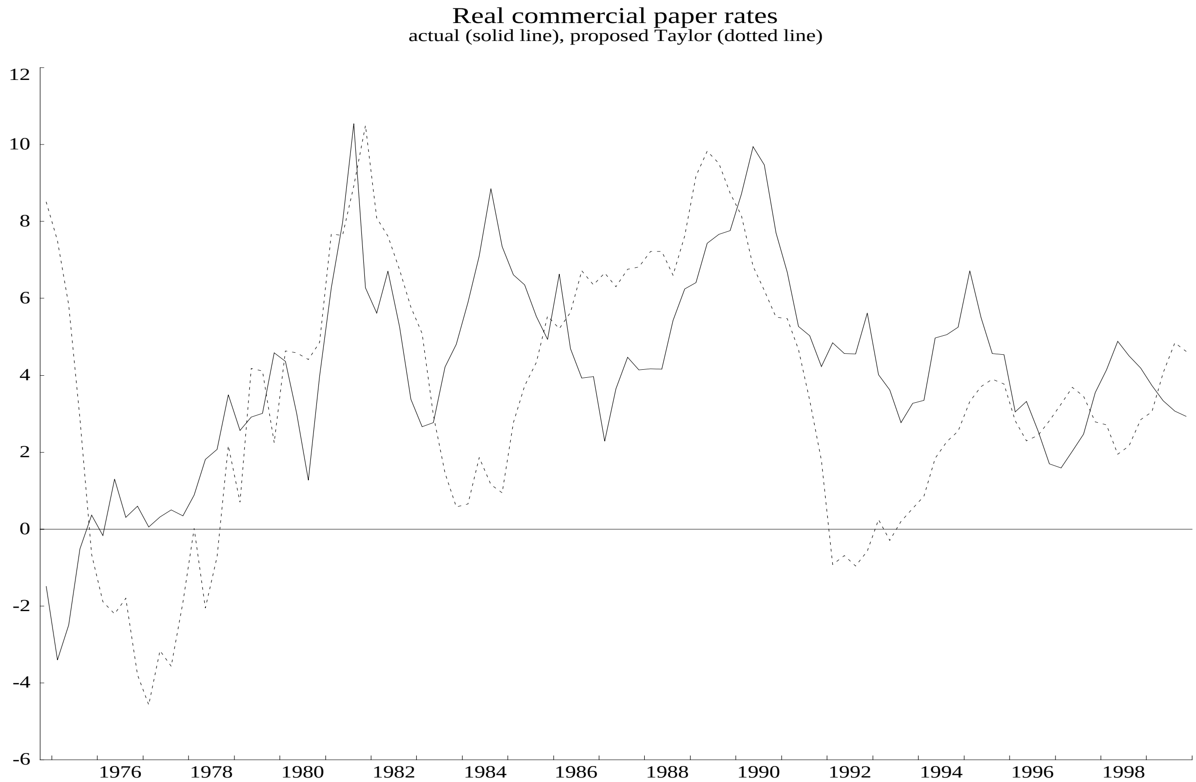



**FIGURE 17: Static Counterfactual Comparing Proposed Taylor-Type Rules**

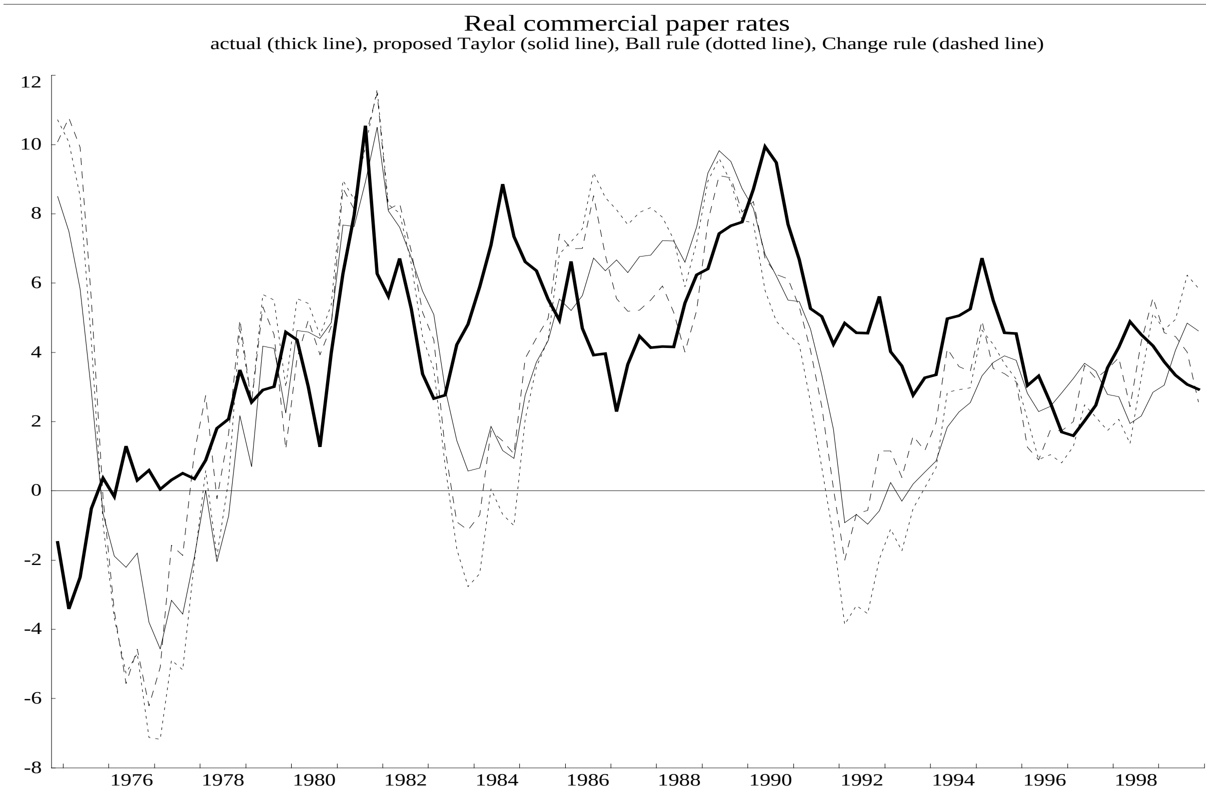
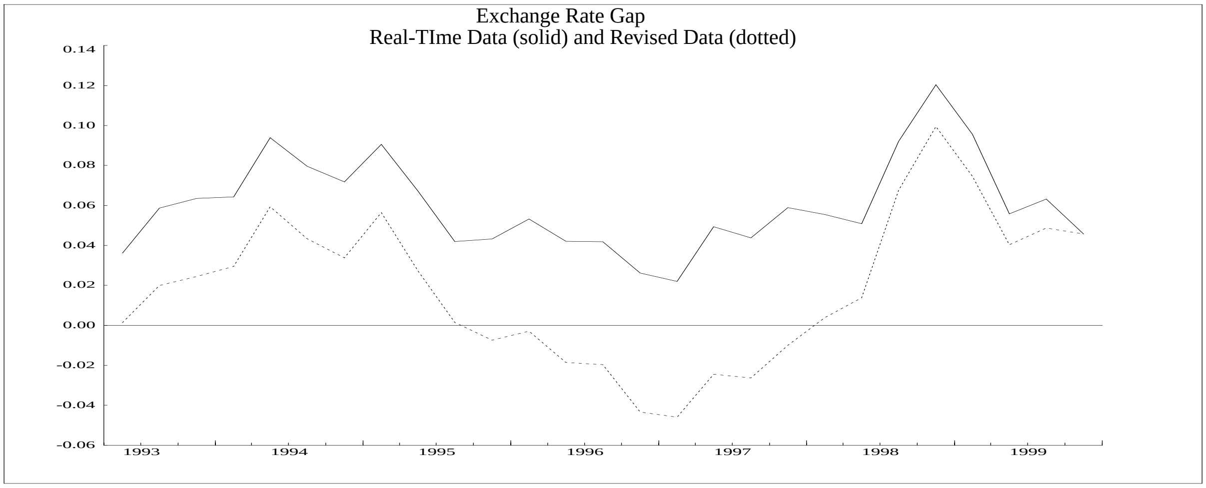
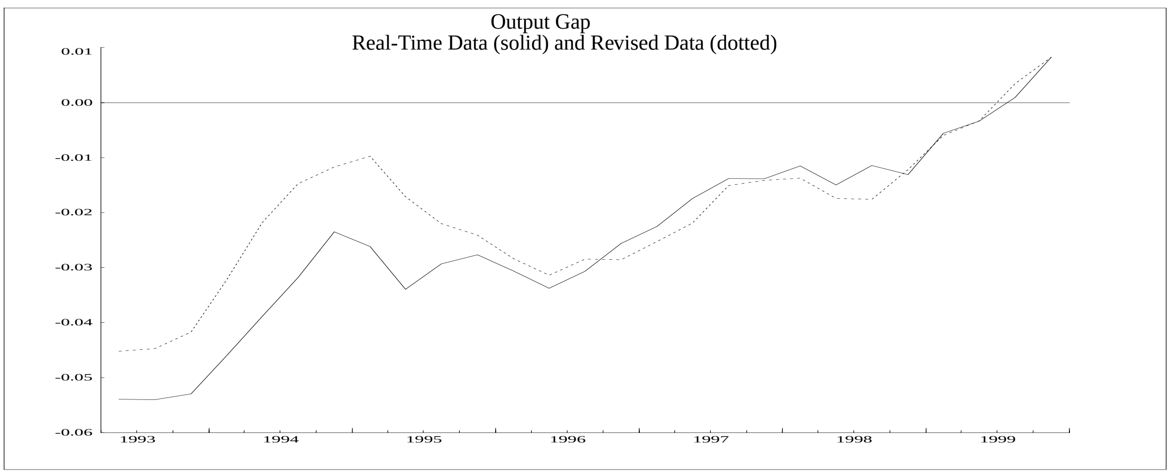


**FIGURE 18: Real-Time versus Revised Data**



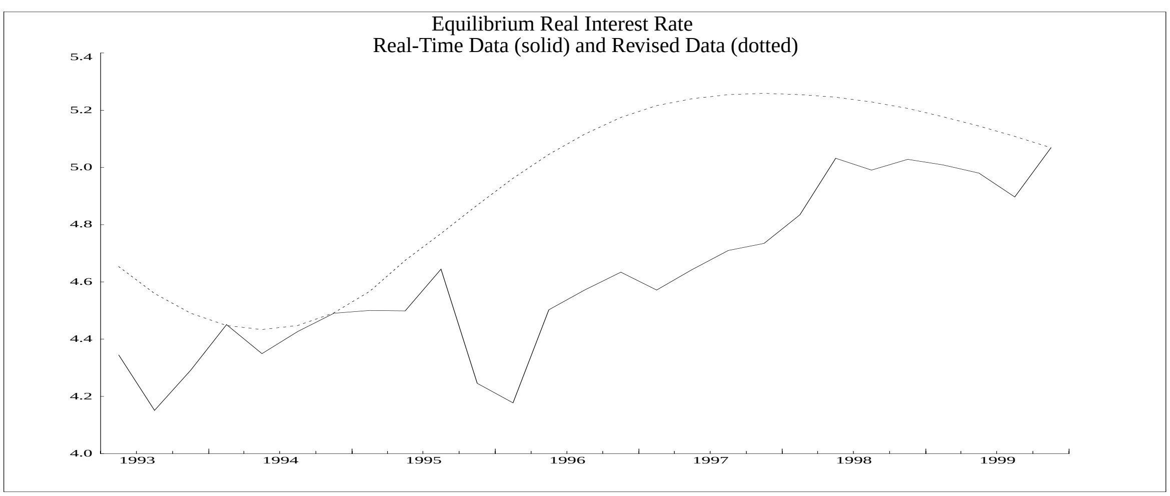
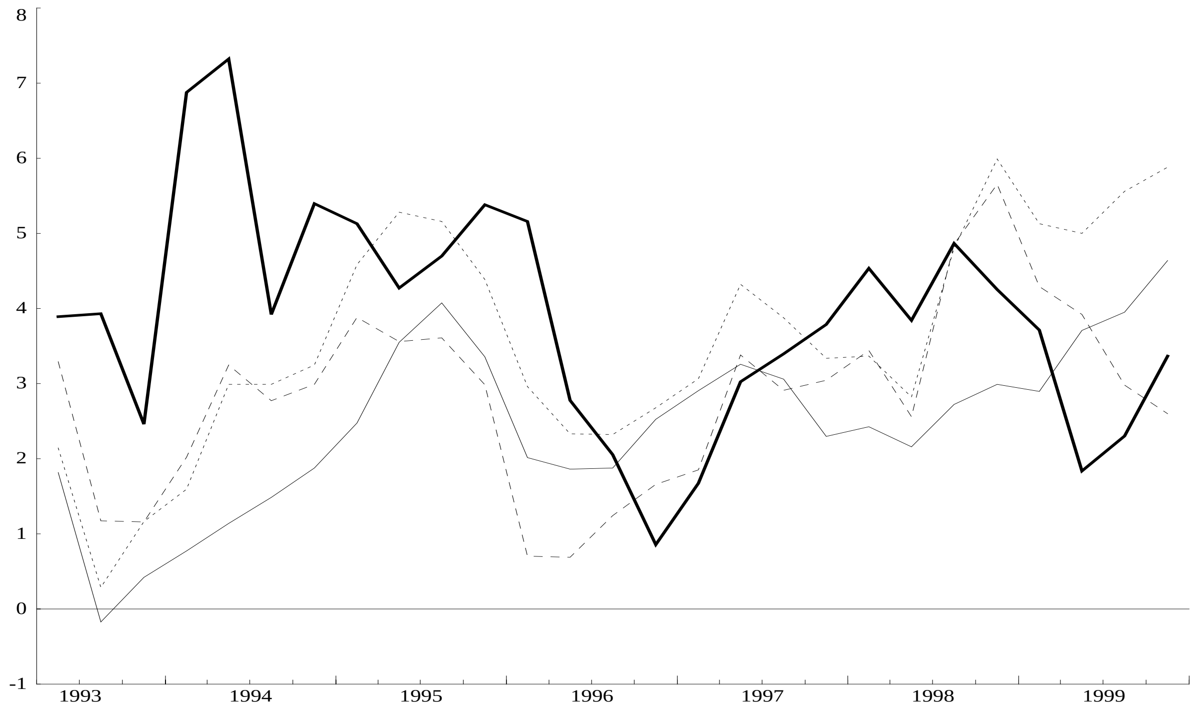
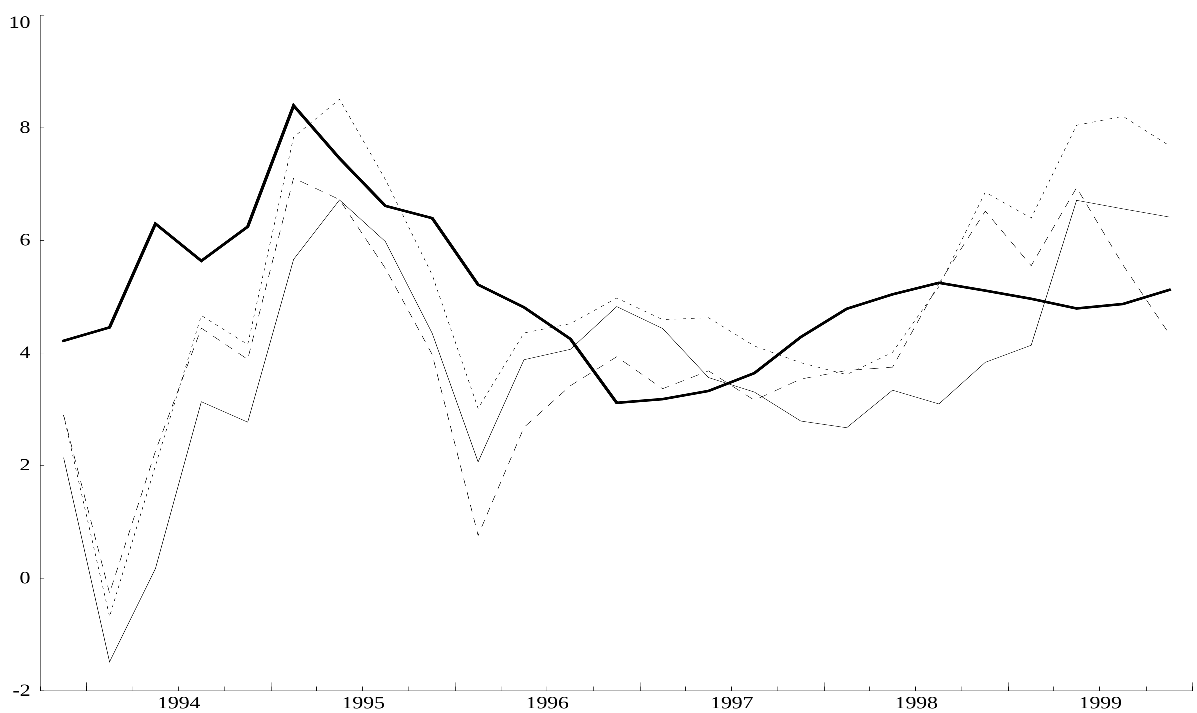



**FIGURE 19: Comparing Rules Using Real-Time Data to Historic Values**

Real commercial paper rates
Real-Time Data
actual (thick line), proposed Taylor (solid line), Ball rule (dotted line), Change rule (dashed line)




Nominal commercial paper rates
Real-Time Data
actual (thick line), proposed Taylor (solid line), Ball rule (dotted line), Change rule (dashed line)



# Appendix

The shocks used in the stochastic simulations are calibrated using an estimation-by-simulation approach.[1] Two different shock calibrations are used in this work: the first to reflect the historical distribution of shocks and the second to give greater exchange rate variability.

In the first calibration, we start with a simple AR(1) representation of innovations, and then re-parameterize them until QPM produces standard deviations and autocorrelation coefficients that match approximately those in the data. In other words, we are trying to match both the mix of shocks and their persistence. In particular, we try to match the variability and autocorrelation of the change in real output, inflation, and the change in interest rates to those values calculated for the period from 1973Q1 to 1998Q1.[2] Shocks are introduced on eight behavioural variables and one exogenous variable (the level of steady-state productivity).[3] Shocks are also introduced for four variables that capture activity in the rest of the world. Table A-1 compares the standard deviations and AR(1) coefficients of this calibration to those calculated for the period 1973Q1 to 1998Q1. To calibrate the variability of interest rates close to the historical variability, the variability of the real exchange rate was kept below that calculated over history.

In comparing open-economy rules such as the Ball rule with the simple Taylor rule, the degree of exchange rate variability has an important influence on the results. A second calibration was tried, therefore, which includes a higher variability of temporary exchange rate shocks. The standard deviation of the real exchange rate was increased to 7.1, close to the historical average of 7.9. The standard deviations and AR(1) coefficients for this calibration are shown in the last two columns of Table A-1.

1. For more details on the estimation-by-simulation approach, and the vector autoregression used to generate the rest-of-world shocks, see Amano, Coletti, and Murchison (1999).
2. The choice of sample period is open to the criticism that variabilities may have altered over time; for example, that output variability has fallen. Sensitivity analysis suggests that the main qualitative conclusions regarding changes in variabilities as rules differ are robust to reasonable changes in the variabilities of output and inflation; however, further research is needed on the calibration.
3. Shocks are included for the GDP deflator, CPI, real consumption, real investment, real exports, real imports, the total direct tax rate, wages, and total factor productivity.

**Table A-1: QPM Sample Moments for Two Calibrations and Historical Standard Deviations and Autocorrelation Coefficients with their Corresponding 95 Per Cent Confidence Intervals**

| | Historical | | Calibration 1 | | Calibration 2 | |
|---|---|---|---|---|---|---|
| Variables[a] | Std Dev | AR(1) Coef. | Std Dev | AR(1) Coef. | Std Dev | AR(1) Coef. |
| Output | | | | | | |
| Quarterly | 3.0 < 3.4 < 3.9 | 0.24 < 0.43 < 0.63 | 4.4 | 0.3 | 4.6 | 0.3 |
| Annual | 2.1 < 2.4 < 2.7 | 0.67 < 0.87 < 1.06 | 2.7 | 0.8 | 2.8 | 0.8 |
| CPI ex. food & energy | | | | | | |
| Quarterly | 3.1 < 3.5 < 4.1 | 0.61 < 0.80 < 1.00 | 2.1 | 0.6 | 2.5 | 0.7 |
| Annual | 2.8 < 3.2 < 3.7 | 0.76 < 0.96 < 1.16 | 1.7 | 0.9 | 2.0 | 0.9 |
| Real G6 exchange rate | | | | | | |
| Quarterly | 6.9 < 7.9 < 9.1 | 0.22 < 0.42 < 0.61 | 3.7 | 0.5 | 7.1 | 0.3 |
| Annual | 4.9 < 5.6 < 6.5 | 0.66 < 0.79 < 1.06 | 2.5 | 0.8 | 4.3 | 0.8 |
| Yield spread | 1.2 < 1.4 < 1.6 | 0.54 < 0.74 < 0.93 | 2.0 | 0.9 | 2.9 | 0.9 |
| 10-year interest rate | 1.9 < 2.2 < 2.5 | 0.73 < 0.93 < 1.12 | 1.8 | 0.9 | 2.4 | 0.9 |
| 90-day interest rate | 3.0 < 3.4 < 4.0 | 0.72 < 0.91 < 1.11 | 3.8 | 0.9 | 5.2 | 0.9 |

a. Quarterly indicates quarterly growth at annual rates. Annual indicates year-over-year growth.

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