Interest-Rate Smoothing versus Serially Correlated Errors in Taylor Rules: Testing the Tests*

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Abstract

This paper contributes to the recent debate about the partial-adjustment coefficient in dynamic Taylor rules, often interpreted as interest-rate smoothing on the part of the monetary authority. We argue that the common finding of a large and significant coefficient on the lagged interest rate may be the consequence of a misspecified central bank reaction function, specifically an omitted variables problem. Our Monte Carlo study shows that omitting relevant variables from the estimated reaction function can generate significant partial-adjustment coefficients, despite the data generating process containing no interest-rate smoothing. We further show that misspecification leads to considerable size distortions in two tests that were proposed recently by English et al. (2003) in order to distinguish between interest-rate smoothing and serially-correlated disturbances.

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1 Introduction

The Taylor (1993) rule has, over the last decade, become a largely unquestioned tool for monetary policy evaluation. Notwithstanding this, a number of authors have recently presented serious criticisms of the Taylor rule, Rudebusch (2002) being among the more influential. Rudebusch uses term-structure evidence to show that a Taylor rule with partial adjustment, interpreted as interest-rate smoothing by the central bank, implies more interest-rate predictability than can be found in the data. In contrast to much of the existing literature, Rudebusch also points to the implausibility of the slow partial adjustment implied by most coefficient estimates. The degree of interest-rate smoothing found in quarterly data implies that the central bank closes the gap between the actual and the desired target interest rate slowly, roughly half of the gap in a year. His explanation for the high degree of interest-rate smoothing commonly found in the literature is the presence of serially-correlated errors caused by '*appropriate response[s] to special circumstances*' which are not captured by the variables in the Taylor rule.

Although almost observationally equivalent, interest-rate smoothing and serially-correlated errors have not only different economic interpretations but also different statistical implications. English et al. (2003), ENS henceforth, use this fact to develop two tests that distinguish between the two cases. Employing these tests and Castelnuovo (2003a,b) find support for interest-rate smoothing when the tests are applied to U.S. data.

The purpose of this paper is to further investigate the reasons for the finding of strong interest-rate smoothing in estimated Taylor rules and our focus is on omitted variables as a likely cause. We employ a Monte Carlo study of a data generating process based on a structural VAR for the U.S. economy and in addition to the federal funds rate, inflation and the output gap, capture dynamics by including four potentially important variables. We investigate the magnitude of the resulting bias in the coefficients of the Taylor rule and the size properties of the ENS tests when the estimated reaction function is misspecified. As expected, estimating a standard Taylor rule with inflation and output gap as only explanatory variables results in biased coefficients when the central bank's true reaction function contains additional persistent variables.[1] The ENS tests are also found to overreject the null hypothesis of no interest-rate smoothing at conventional significance levels. While our exercise does not reproduce the degree of interest-rate smoothing that is commonly found in empirical studies, the results in this paper suggest that the ENS tests must be interpreted with caution and that upward bias of the partial-adjustment coefficient can be sizeable.

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[1] An early source is Griliches (1961).

The methodological setup in this paper takes as it starting point critique of Svensson (2003, 2005) that the Taylor rule is unlikely to be the solution to a typical central bank optimisation problem of stabilising inflation and the output gap. If important state variables other than inflation and the output gap exist, the rule will not be optimal; instead, the number of response coefficients that need to be fixed in the central bank's reaction function must be increased in accordance with the number of state variables the central bank takes into account.Put differently, inflation and output deviations are unlikely to be sufficient statistics for the state of the economy, nor for characterisation of central bank behaviour.[2] Svensson's arguments are also empirically relevant. For instance, Österholm (2005) points out that given the highly persistent nature of variables in the Taylor rule, cointegration is a necessary condition for both consistent estimation of parameters and compatibility between theoretical models and data. The lack of empirical evidence for a cointegrating relationship between nominal interest rates, inflation and the output gap thus offers support for the idea that the Taylor rule is misspecified. Furthermore, Goodhart and Hofmann (2002) show how the omission of various asset price variables leads to considerable changes in the remaining coefficients in an estimated Taylor-type rule.

The remainder of this paper is organised as follows. Section 2 presents the Taylor rule and replicates some well-known empirical results. In Section 3, the ENS test equations are presented. Section 4 describes the data generating process (DGP) used in the Monte Carlo study, the results of which are discussed in Section 5. Section 6 concludes with a brief discussion of our findings and some general remarks.

2 The Taylor Rule

To organise the discussion, we first give an account of the Taylor rule and then provide a brief overview of the theoretical and empirical literature on interest-rate smoothing. A more thorough exposition can be found in Taylor (1999).

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[2] This viewpoint finds support among practitioners. For instance Ben S. Bernanke (2004), member of the Board of Governors of the U.S. Federal Reserve System, remarked: '..., *my forecast of controlled inflation is based on more than output gap arguments. Other factors likely to keep inflation at modest levels include continuing rapid gains in productivity, which have kept growth of unit labor costs at a very low level; unusually high price-cost margins in industry, which provide scope for firms to absorb future cost increases without raising prices; globalization and intensified competition in product markets; and the recent strengthening of the dollar.*'

2.1 Basic Specification and Empirical Evidence

The original formulation of the Taylor (1993) rule is given by

$$i_t = r^* + \pi_t + f_\pi (\pi_t - \pi^*) + \phi_y y_t, \tag{1}$$

where i_t is the central bank policy rate, r^* the equilibrium real interest rate, π_t the twelve month inflation rate, π^* the inflation target of the central bank and y_t the output gap. Based on calibration, Taylor found that a rule with the parameters set to $r^* = \pi^* = 2$ and $f_\pi = \phi_y = 0.5$ tracked the actual federal funds rate fairly well between 1987 and 1992. Note that the equilibrium real interest rate as well as the inflation target are assumed to be constant here.

Adding an error term and collecting constants in the intercept, equation (1) can be reformulated as

$$i_t = \phi_0 + \phi_\pi \pi_t + \phi_y y_t + \varepsilon_t^i, \tag{2}$$

where $\phi_0 \equiv r^* - (\phi_\pi - 1)\pi^*$ and $\phi_\pi \equiv 1 + f_\pi$. The rule in equation (2), or versions thereof allowing for forward-looking behaviour, has been the standard starting point in the empirical literature.[3]

In the literature, it has also been shown that adding a lagged interest rate term as

$$i_t = (1 - \lambda)\left(\phi_0 + \phi_\pi \pi_t + \phi_y y_t\right) + \lambda i_{t-1} + \varepsilon_t^i, \tag{3}$$

where $0 \leq \lambda < 1$, improves the empirical fit considerably. The lagged interest-rate term is commonly interpreted as deliberate interest-rate smoothing on the part of the monetary authority. Note also that equation (3) has a partial adjustment structure in which the term $\widetilde{i_t} \equiv \phi_0 + \phi_\pi \pi_t + \phi_y y_t$ is the target interest rate dependent on the state of the economy that the central bank seeks to achieve.

As an example of a typical finding in the empirical literature, we present the results from least squares regressions of the static equation (2) and the dynamic equation (3) using quarterly U.S. data on the federal funds rate, CPI inflation and output gap from 1987Q1 to 2004Q3.[4] Newey-West standard errors are reported in parentheses and results for the constants have been omitted here for brevity.

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[3] An extensive discussion in the literature addresses the timing of explanatory variables in the Taylor rule. For example, McCallum and Nelson (1999) have argued that due to informational delays, the central bank likely reacts to lagged values of inflation and the output gap. Others have suggested using forecasts of the regressors in order to capture the potentially forward-looking behaviour of central banks. For a study which addresses several different approaches, see Orphanides (2001). The timing issue is less relevant for the exercise in this paper because the data are generated synthetically. We therefore adhere to Taylor's original formulation regarding timing.

[4] All data are from the Federal Reserve Bank of St Louis data base (FRED).

The results for the estimated static Taylor rule are shown in (S). The estimated coefficients are not far from those suggested by Taylor (1993)[5] but the diagnostic test statistics indicate the presence of autocorrelation as well as heteroskedasticity in the residuals.

$$\begin{aligned} i_t &= \underset{(0.12)}{1.32}\,\pi_t + \underset{(0.13)}{0.77}\,y_t \\ &\quad R^2_{adj} = 0.78 \quad \widehat{\sigma}_\varepsilon = 1.05 \quad DW = 0.38 \\ &\quad AR(4) : \chi^2(4) = 42.05 \quad ARCH(4) : \chi^2(4) = 28.15 \end{aligned} \tag{S}$$

The estimated dynamic Taylor rule (D) appears to fit the data better, with a higher adjusted R^2 and standard error halved relative to the static equation. The coefficient estimates are markedly different, with the restriction $\phi_y = 0.5$ rejected at the 5 percent level while the restriction $\phi_\pi = 1.5$ is not. Despite inclusion of the lagged dependent variable, the autocorrelation tests still indicate serial correlation in the residuals.

$$\begin{aligned} i_t &= 0.17\,(\,\underset{(0.34)}{1.21}\pi_t + \underset{(0.21)}{1.30}y_t\,) + \underset{(0.04)}{0.83}\,i_{t-1} \\ &\quad R^2_{adj} = 0.97 \quad \widehat{\sigma}_\varepsilon = 0.41 \quad DW = 0.75 \quad Durbin\ H = 5.62 \\ &\quad AR(4) : \chi^2(4) = 27.03 \quad ARCH(4) : \chi^2(4) = 14.42 \end{aligned} \tag{D}$$

It is surprising how many researchers have interpreted the estimated partial adjustment coefficient as evidence of intentional interest-rate smoothing by the central bank, despite the basic fact that all coefficients in this equation are inconsistently estimated because of the significant lagged dependent variable together with autocorrelated disturbances. Clarida et al. (1998, 2000), Gerlach and Schnabel (2000) and Doménech et al. (2002) study dynamic Taylor rules over different sample periods across different countries and consistently report large and significant smoothing parameters. Each interpret these estimates as evidence for the hypothesis that central banks adjust their policy interest rate very gradually towards the target interest rate. This conclusion is questionable, however, given the implied speed of adjustment of similar parameter estimates. The implication of our estimation of (D) with quarterly data is that almost a year elapses before the monetary authority closes *half* of the gap between the actual federal funds rate and the intended interest rate target. The value of 0.92 found by Clarida et al. (1998) using U.S. monthly data from 1979 to 1994 implies that approximately half the intended adjustment has taken place after about nine months. Even though there seems to be agreement in the profession that central banks dislike aggressive movements of their instruments because such behaviour is believed to unsettle financial markets, the adjustment implied by these estimates seems implausibly slow. More generally, Hendry (1995, p. 259) remarks that '*long lags in partial adjustment models may be an artefact of that type of model*', and further notes

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[5] The restrictions $\widehat{\phi}_\pi = 1.5$ and $\widehat{\phi}_y = 0.5$ are not rejected at the 5 percent level.

that the adjustment parameter often lies in the interval (0.8, 0.95) '*regardless of application'*. These econometric issues raise doubts over the appropriateness of the dynamic Taylor rule in equation (3).

2.2 Related Literature

A wealth of theoretical literature has investigated whether interest-rate smoothing is optimal from a monetary policy perspective. The results are not clear cut and are dependent on the structural macroeconomic model. Aoki (2003), for example, shows that interest-rate smoothing may be optimal in the presence of noisy indicator variables because it allows policy cautiousness in the presence of uncertainty. Woodford (2003) establishes that in a purely forward-looking model with commitment to optimal policy, a lagged interest-rate term in the monetary reaction function may be optimal because it induces history dependence that helps to stabilise inflation expectations. Using larger models Levin et al. (1999) suggest that interest-rate smoothing in the short-term interest rate may provide control over long-term rates, because expected sustained movements of the short-term interest rate have a greater impact on long-term interest rates.

In an empirical study, Goodhart (1997) investigates the interest rate setting behaviour of several central banks and finds that they tend to move the interest rate in small steps in the same direction between reversals. This observation does not, however, provide direct justification for interest-rate smoothing. Slow, stepwise movements in the interest rate may reflect an explicit smoothing objective or be the appropriate reaction to the central bank's perception of the slow-moving state of the economy.

In a follow-up study to Rudebusch (2002), Söderlind et al. (2005a) find that the two sides of the Taylor rule do not match in terms of predictability. The inflation rate and output gap are relatively easy to predict, which should imply predictability of nominal interest rate changes, but the authors find that survey evidence does not support this conclusion. In a companion paper, the same authors find a high preference for interest-rate smoothing and almost no preference for output gap stabilisation in a model with optimal, discretionary monetary policy (Söderlind et al., 2005b). This may be a particular result of that type of model.

3 Two Tests for Interest-Rate Smoothing

This section reviews the testing procedure suggested by English et al. (2003). In the standard empirical specification, the error term ε_t^i in (2) is assumed to be serially uncorrelated. However, as pointed out by Rudebusch (2002), serial correlation may give rise to a significant coefficient on the lagged interest rate (Grilliches, 1961). Assuming that error autocorrelation is of first order, the interest rate equation may be specified as

$$i_t = \phi_0 + \phi_\pi \pi_t + \phi_y y_t + \upsilon_t, \qquad \upsilon_t = \rho \upsilon_{t-1} + \varepsilon_t^i, \tag{4}$$

where ε_t^i is assumed to be *i.i.d.* with mean zero. Subtracting i_{t-1} from both sides and again letting $\widetilde{i}_t \equiv \phi_0 + \phi_\pi \pi_t + \phi_y y_t$ denote the target rate of the central bank, equations (3) and (4) can both be rewritten in the form

$$\Delta i_t = \gamma_1 \Delta \widetilde{i}_t + \gamma_2 \left(\widetilde{i}_{t-1} - i_{t-1} \right) + \varepsilon_t^i. \tag{5}$$

The parameter γ_1 indicates if the lagged interest rate is significant; with interest-rate smoothing, $\gamma_1 = \gamma_2 = 1 - \lambda$, but with serially-correlated errors $\gamma_1 = 1$ and $\gamma_2 = 1 - \rho$. English et al. (2003) suggest a test for serial correlation versus interest-rate smoothing that can be based on a non-linear least squares estimation of equation (5). Note, that the hypotheses are not nested; rejecting the null hypothesis $H_0 : \gamma_1 = 1$ is not sufficient to conclude interest-rate smoothing but also requires maintaining the hypothesis that $\gamma_1 = \gamma_2$. From this point of view, a likelihood ratio test might be preferable to a simple coefficient test as conducted by English et al. (2003).

In order to obtain a nested test equation, the authors extend the model to a more general form and allow for both interest-rate smoothing and serially-correlated errors in one specification, that is,

$$i_t = (1 - \lambda) \widetilde{i}_t + \lambda i_{t-1} + \upsilon_t, \qquad \upsilon_t = \rho \upsilon_{t-1} + \varepsilon_t^i. \tag{6}$$

They estimate equation (6) on U.S. data and find significant estimates of λ and ρ. As we will show below, this test procedure may be misleading if the coefficients in (6) are biased due to omitted variables that are not proxied by the autocorrelated error term. English et al. (2003) also address whether a significant smoothing parameter may be spuriously obtained due to omitted variable bias but consider measurement error, parameter instability and changed levels of the target variables as likely culprits. Castelnuovo (2003b) tests for omitted variables in the same framework and finds that the square of the output gap[6] and the growth rate of M3 are both significant when individually included in the equation. However, he still finds that the interest-rate smoothing parameter is significant and draws the conclusion that its magnitude adequately describes the degree of interest-rate smoothing.

In the following we will investigate the importance of omitted variable bias for the above equations. For this purpose we base our Monte Carlo study on equations (3) to (6)

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[6] This is taken to represent asymmetric preferences of the central bank; see for instance Surico (2002).

and study the influence of omitted variables on (i) the partial adjustment coefficient and (ii) the empirical size of the tests.

4 Model and Data Generating Process

The model used for the simulations is based on a structural VAR for the U.S. economy incorporating short-run restrictions.[7] Estimation is performed using quarterly data from 1987Q1 to 2004Q3 on inflation (π_t), the output gap (y_t), the log-difference of M2 ($\Delta m2_t$), the yield on the ten year treasury bond (i_t^{10y}), the log-difference of the Standard and Poor 500 index ($\Delta sp500_t$), the log of the real effective exchange rate (q_t), and the Federal funds rate (i_t). All data are from the Federal Reserve Bank of St. Louis data base (FRED), apart from the S&P 500 index which was taken from EcoWin Pro. We define inflation as $\pi_t = 0.25\sum_{s=0}^{3}\widetilde{\pi}_{t-s}$, where $\widetilde{\pi}_{t-s} = 400\ln(P_t/P_{t-1})$ and P_t is the consumer price index. The output gap is defined as $y_t = 100\ln\left(\widetilde{y}_t/\widetilde{y}_t^{pot}\right)$, where $\widetilde{y}_t$ is GDP and $\widetilde{y}_t^{pot}$ potential GDP.

The structural VAR is estimated in order to find a reasonable summary of the data dynamics and covariances and to identify a monetary policy reaction function. No attempt is made to build a structural model – such as a DSGE model – of the economy. We first determine the lag length of the unconstrained VAR to be unity according to the Schwarz information criterion. Having established the lag length, we next turn to estimation of the model. Let the general form of the model be given by

$$A_0 x_t = \mu + A_1 x_{t-1} + \varepsilon_t, \tag{7}$$

where x_t is the 7×1 vector of our macroeconomic variables, $\varepsilon_t \sim nid(0, D)$ and D is a diagonal matrix. Specifically $x_t = [\pi_t \; y_t \; z_t \; i_t]'$, where z_t is the vector containing the additional four variables money growth, long term interest rate, change in S&P 500 and the real effective exchange rate (in that order).

We assume a recursive identification scheme in which the interest rate is ordered last for two reasons: (i) it has been widely used in the literature (Christiano et al., 1999; Sims, 1980), and (ii) we are not concerned with shocks in the economy.[8] The main advantage of this identification assumption is that ordering the policy interest rate last in the recursion allows the central bank to react to all the other variables in the system contemporaneously. This is in line with the fairly general opinion that the central bank takes a large number of variables into account in its decision making. Second, and more importantly, the recursive

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[7] A K-model in the terminology of Amisano and Giannini (1997).

[8] For a range of identification approaches, see Bernanke (1986), Shapiro and Watson (1988), Blanchard and Quah (1989) and Uhlig (2005).

structure means that we can identify the monetary policy innovation without having to define seven structural equations.

We fix the contemporaneous coefficients on inflation and the output gap in the interest rate equation to 1.5 and 0.5, respectively, in accordance with Taylor's original article and the general findings in the literature. Furthermore, because we want to study the effects of omitted variables in a static Taylor rule, we set all lags in the interest rate equation to zero when we estimate the system (7). All other coefficients are estimated without restrictions. Given the recursive structure of the system, we can consistently estimate it equation-by-equation with OLS.[9]

Having estimated the above model, we use the coefficient estimates $\widehat{A}_0$, $\widehat{A}_0$, $\widehat{\mu}$, $\widehat{D}$ to generate synthetic data. These data meet all of our underlying assumptions, enabling us to investigate the properties of the suggested econometric tests for an economy with serially-uncorrelated shocks and a central bank that does not employ interest-rate smoothing but does react to four additional macroeconomic variables.

5 Simulations and Results

The Monte Carlo experiment consists of 10 000 replications of the economy simulated for 100 periods. Because our purpose is to study the effects of omitted variables bias, we estimate equations (3) to (6) on the generated data, omitting the four additional variables that are part of the true DGP. We then perform hypothesis tests on $\gamma_1, \gamma_2, \lambda$ and ρ as suggested by English et al. (2003).

5.1 Results

Table 1 presents the direct estimates of the smoothing coefficient, λ, from equation (3) while Figure 1 shows the empirical distribution function.[10] The results for the autocorrelation coefficient, ρ, estimated from equation (4) are summarised in Table 2 and Figure 2. We report the median and the 5^{th} and 95^{th} percentiles of the empirical distribution function of the estimated coefficients. The vertical line in the histograms indicates the true value in the DGP.

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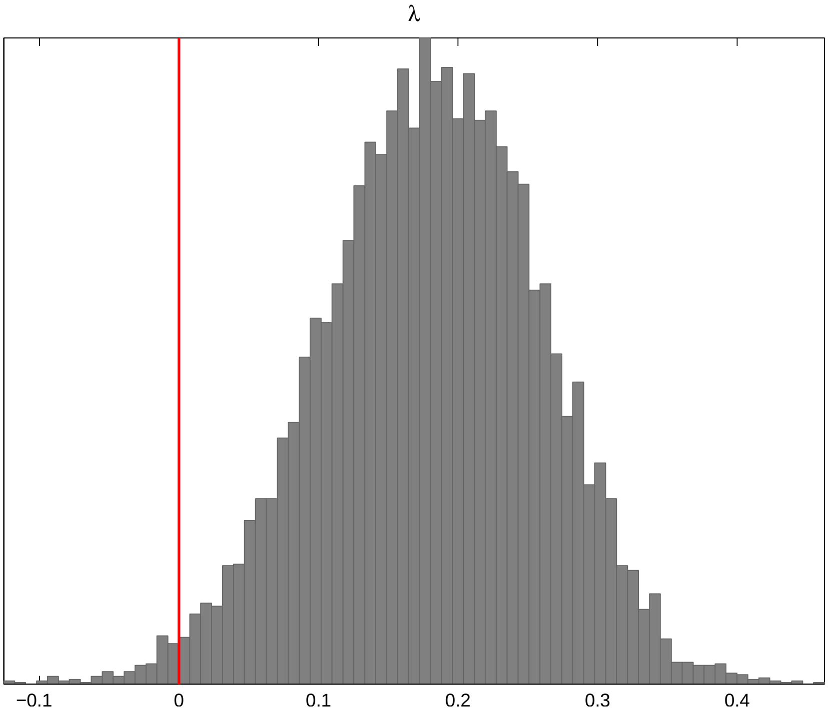
[9] The restricted VAR is a recursive simultaneous equation system with diagonal variance-covariance matrix.

[10] Instead of estimating equation (3) with non-linear least squares, the equivalent model $i_t = \beta_0 + \beta_\pi \pi_t + \beta_y y_t + \lambda i_{t-1} + \varepsilon_t^i$ was estimated and the coefficients were thereafter transformed to long-run values in order to be comparable to the other estimated coefficients in the paper.

Table 1: First Test under the Assumption of Interest-Rate Smoothing

Parameter	Median	5,95 percentile	true value
λ	0.18	[0.05,0.31]	0
ϕ_π	1.79	[1.53,2.05]	1.5
ϕ_y	0.59	[0.43,0.75]	0.5

Figure 1: First Test under the Assumption of Interest-Rate Smoothing



Notes: Empirical distribution function of the partial adjustment coefficient λ, obtained from 10 000 OLS estimations of equation (3).

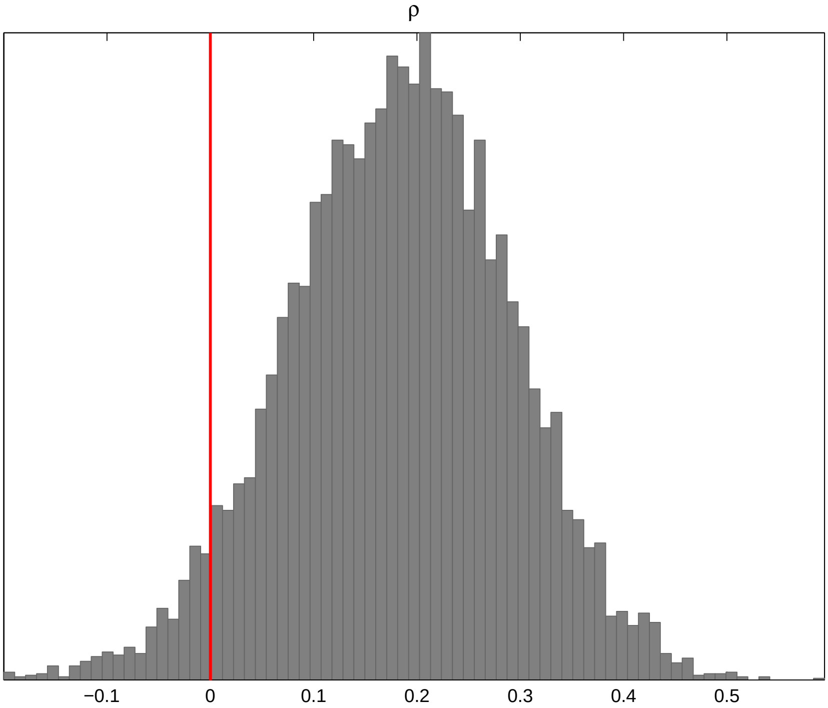
The results in Table 1 reveal that all coefficients are biased. Specifically, the distribution of λ has its median at 0.18, suggesting the presence of interest-rate smoothing. This is a standard econometric result: omitting the four additional variables causes the residuals to be autocorrelated and this autocorrelation is taken up by the lagged interest rate term in (3) and the autocorrelation term in equation (4). The autocorrelation correction only succeeds if the omitted variables are orthogonal to inflation and the output gap, which is neither the case in this experiment nor likely to be true in real data.

These two cases demonstrate the difficulty in distinguishing between interest-rate smoothing and serially-correlated errors when tested one at a time and are the motivation for the reduced-form equation (5) suggested by English et al. (2003). As explained before, the assumption underlying this equation is that only one of the two alternatives is

Table 2: First Test under the Assumption of Serially Correlated Errors

Parameter	Median	5,95 percentile	true value
ρ	0.19	[0.00,0.35]	0
β_π	1.76	[1.50,2.00]	1.5
β_y	0.55	[0.39,0.70]	0.5

Figure 2: First Test under the Assumption of Serially Correlated Errors



Notes: Empirical distribution function of the serial correlation coefficient ρ, obtained from 10 000 NLLS estimations of equation (4).

true, even though the two are nested in the same equation. Hence, $\gamma_1 < 1$ would indicate that the coefficient on the lagged interest rate is significant. We present the Monte Carlo results for equation (5) in Table 3 and Figure 3.

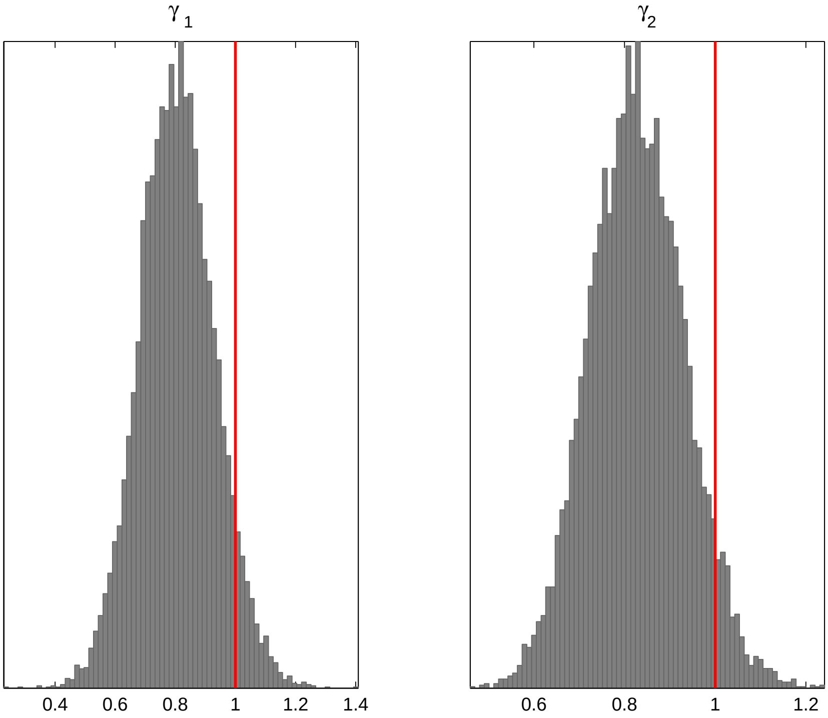
These results once again show that all coefficients are biased. In particular, the reduced form parameter γ_1, which provides an indication of the degree of interest-rate smoothing, is biased downward. In fact, the medians of γ_1 and γ_2 are almost equal, pointing to interest-rate smoothing in the data rather than autocorrelated errors. This is confirmed by a Wald test with the null hypothesis that the two coefficients are equal; at the 5 percent level, this test rejects the null in only 7 percent of cases.

Next we discuss the results from the model permitting both interest-rate smoothing and autocorrelated errors. Table 4 shows the estimated parameters and Figure 4 displays

Table 3: First Test for the Reduced Form

Parameter	Median	5,95 percentile	true value
γ_1	0.81	[0.61,1.02]	1
γ_2	0.83	[0.66,1.00]	1
ϕ_π	1.79	[1.53,2.06]	1.5
ϕ_y	0.59	[0.43,0.75]	0.5

Figure 3: First test for the Reduced Form



Notes: Empirical distribution function of the reduced form coefficients γ_1 and γ_2, obtained from 10 000 NLLS estimations of equation (5).

the empirical distribution function.

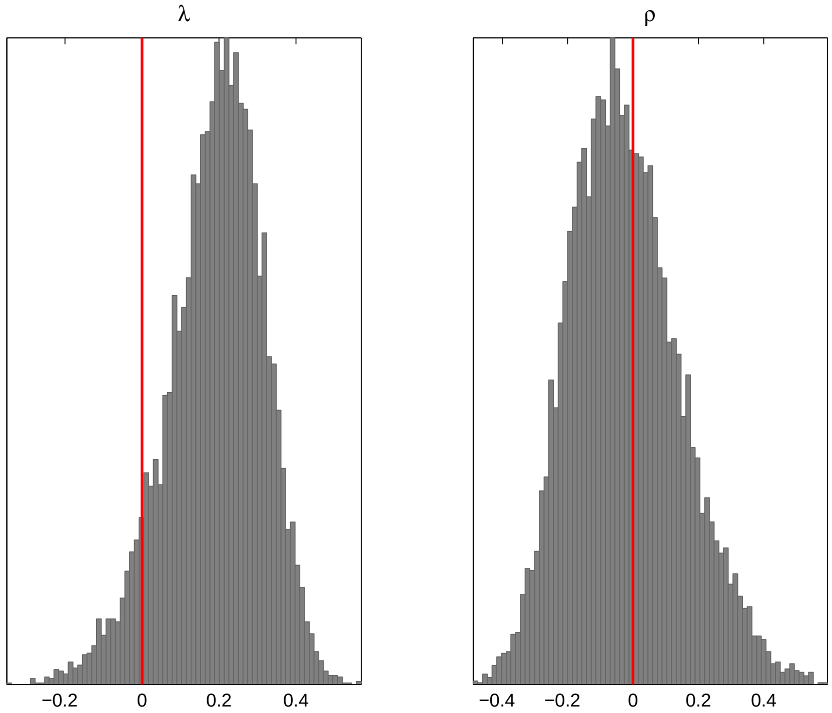
The Monte Carlo results imply that there is interest-rate smoothing rather than serial correlation in the errors, in line with our results from equation (5). Bias in the inflation and output-gap coefficients has been reduced, but the magnitude of the bias in λ is substantial, even though the distribution of λ does not cover the values that are commonly found in empirical studies.

For reference we also report the empirical test sizes in Table 5. These are severely distorted, in line with our expectations based on the coefficient estimates. Interestingly, for our specific data generating process, the omission of relevant explanatory variables leads to the conclusion that partial adjustment explains the dynamics of the data better

Table 4: Second Test: Allowing for Smoothing and Serial Correlation

Parameter	Median	5,95 percentile	true value
λ	0.20	[-0.03,0.37]	0
ρ	-0.04	[0.66,0.28]	0
ϕ_π	1.44	[1.23,1.65]	1.5
ϕ_y	0.47	[0.34,0.61]	0.5

Figure 4: Second Test: Allowing for Smoothing and Serial Correlation



Notes: Empirical distribution function of the reduced form coefficients λ and ρ, obtained from 10 000 NLLS estimations of equation (6).

than a static or dynamic relation with autocorrelated errors.

The exercise demonstrates that modelling autocorrelated errors with autoregression is the wrong cure in this case and leads to incorrect conclusions about the dynamic behaviour of the interest rate.

6 Discussion and Conclusion

The present study investigates the extent to which omitted variables can generate spurious interest-rate smoothing in an otherwise standard Taylor rule. Our results indicate that the tests suggested by English et al. (2003) may not be able to distinguish between

Table 5: Documenting the Distortion of the Test Size

Equation	H_0	Rejection rates - Nominal size 0.05 Empirical rejection rate
(3)	$\lambda = 0$	0.76
(4)	$\rho = 0$	0.54
(5)	$\gamma_1 = 1$	0.36
(5)	$\gamma_1 = \gamma_2$	0.07
(6)	$\lambda = 0$	0.57
(6)	$\rho = 0$	0.06

Notes: Wald test on $H_0 : \gamma_1 = \gamma_2$. All other tests are (one-sided) t-tests.

interest-rate smoothing and serially-correlated disturbances in Taylor-type rules when the rule is misspecified. The omission of relevant variables leads to biased and inconsistent coefficient estimates and is likely to induce a disturbance structure for which the tests are not designed. However, the smoothing coefficient that we obtain is not as high as is commonly found in empirical studies and we cannot draw further conclusions about the magnitude of the partial adjustment coefficient in real data. Nevertheless, our analysis demonstrates that autocorrelation does not entail autoregression and that the interest-rate smoothing term is likely to have a sizeable upward bias when important variables are omitted from the Taylor rule. It also suggests that inference regarding central banks' preferences could be hazardous if there is reason to believe that the monetary policy reaction function is incorrectly specified.

The results of this paper question the standard conclusion that the large and significantly estimated coefficient on the lagged interest rate should be interpreted as intentional interest-rate smoothing. The partial adjustment coefficient may not be informative about the true degree of interest-rate smoothing because it may hide omitted variable bias due to misspecification of the estimated equation and its disturbance structure. This finding not only raises doubts about conclusions from the Taylor-rule literature evaluating central bank performance and preferences but offers a credible explanation for the inconsistencies between the Taylor rule and the data that have recently been brought to researchers' attention.

Variable omission is a likely source of misspecification in estimated central bank reaction functions. The practical decision-making process in central banks depends on a wider range of economic indicators than inflation and the output gap, including such variables as monetary aggregates, the exchange rate, the current account and financial market variables. The information content of this broad set of indicators may not be sufficiently approximated by inflation and the output gap. It may be reasonable to include forecasts of the output gap and inflation rather than their current values or the determinants for these forecasts. Moreover, as pointed out by Svensson (2003, 2005) and evident from central bank communications, judgement plays an important role in the decision-making process. How this judgement can be accounted for in a statistically sensible way is beyond the scope of this paper.

At a more general level, we can relate our study to macroeconomic modelling methodology. English et al. (2003) point out that serially-correlated errors signal that something systematic has been left out of the estimated equation and name one important implication: as long as the omitted variables that generate the serially-correlated error term are orthogonal to the regressors in the equation, modelling them as autoregressive process is a valid approach. However, this orthogonality assumption is difficult to justify with macroeconomic data. We believe that it is extremely rare for a central bank to observe and react to variables that are orthogonal to inflation and the output gap.

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