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Discussion Paper Series

Asymmetric Interest Rate Effects for the UK Real Economy

By

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May 2002
Number 010

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This paper is preliminary. Please do not quote without permission from the authors. Financial support from the Leverhulme Trust and ESRC grant L138251002 is gratefully acknowledged. We also acknowledge that the GAUSS programs used here derive from programs made available by Timo Teräsvirta. We would like to thank Dick van Dijk, Mike Artis, Ian Garrett and an anonymous referee for helpful comments and other assistance.

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ABSTRACT

Recent literature has uncovered asymmetries in the response of real output to monetary policy variables. Nevertheless, it remains unclear whether such asymmetries relate to different responses to monetary policy or to the business cycle. This paper uses nonlinear models to examine the issues in the context of interest rate effects on quarterly UK GDP growth. Strong evidence of nonlinearity is found, with asymmetry relating to the business cycle through lagged GDP regimes and interest rate changes. The results suggest that interest rate effects on GDP are larger when either lagged growth has been high or when interest rates have substantially increased in the past. However, the inclusion of interest rate regimes without taking account of GDP regimes yields an unsatisfactory model.

Keywords: monetary policy, business cycle asymmetries, smooth transition models, forecasting

JEL Class: C51, C52, E37, E52

I. Introduction

The role of interest rates in the UK economy is a very topical issue. Since the Bank of England was given responsibility in 1997 for controlling inflation, its Monetary Policy Committee has used short-term interest rates as the tool for achieving its inflationary target. Although it is widely acknowledged that monetary policy also affects the real economy, the extent of this influence remains an issue for debate. Therefore, when considering possible trade-offs between failure to meet its inflation target and possible adverse effects of interest rate increases on real activity, the Monetary Policy Committee has no firm foundation on which to judge the latter.

One specific area of debate concerns asymmetries in the effects of monetary policy on the real economy. Such asymmetry was widely accepted by economists in the period subsequent to the Great Depression, when monetary policy was seen as ineffective in combating recession (Johnson, 1962, p.365). Linear models, with their implied symmetry, held sway during the 1970s and 1980s, but a number of recent empirical studies have again returned to the issue and found evidence of asymmetry. One strand of this literature is based on regime-switching models with the regime defined in terms of the value (sometimes simply the sign) of a monetary variable. Many studies of this type have been undertaken for the US, including Choi (1999), Cover (1992), DeLong and Summers (1988), Morgan (1993) and Ravn and Sola (1996), while Karras (1996) considers European countries. All these authors find evidence of asymmetry, with different effects on real output of shocks to money or interest rates depending on the monetary regime.

The second strand of this literature returns to the postwar issue of the effectiveness of monetary policy over the phases of the business cycle, by assuming that nonlinearity is associated with the growth of output. In this context, Garcia and Schaller (1995) find that US monetary policy is more effective during recessions than expansions; similar results are also obtained by Weise (1999). On the other hand, Thoma (1994) finds asymmetry associated with both the sign of the monetary shock and the business cycle phase, with negative shocks having greater effects in periods of high growth. For the task of predicting US recessions, the studies of Anderson and Vahid (2001) and of Estrella and Mishkin (1998) emphasise the importance of the interest rate spread. In the UK context, Simpson, Osborn and Sensier (2001) investigate a business cycle regime model for output growth, with the regime transition probabilities functions of interest rate changes. They find that large increases in interest rates affect the expansion to recession probability, with little role for interest rates in the switch from recession to expansion. Their findings are compatible with the initial postwar view that interest rates are ineffective in combating recession, but contrast to recent US results of Garcia and Schaller (1995) and Weise (1999).

Most of the studies referred to above use small vector autoregressive (VAR) systems to capture the interrelationships between the real and monetary variables under study. These VAR systems typically either assume that the same type of nonlinearity (arising through common regimes defined in terms of a single variable) applies to all equations of the system, or that the nonlinearity is confined to the output equation. Either of these assumptions is contentious.

Of the studies that justify the use of nonlinear models from the perspective of economic theory, Cover (1992), Morgan (1993), Ravn and Sola (1996) and Weise (1999) all use arguments based on prices being less flexible downward than upward. It is indisputable that relative downward price inflexibility may be a source of nonlinearity in these models, but placing too strong a reliance on this explanation ignores other possible sources of nonlinearity. One such source has been highlighted in recent research that has explicitly investigated the nature of monetary policy rules used by central banks. Here evidence has been found of asymmetry in the design of monetary policy, with this asymmetry associated either with the sign of the deviation of inflation from its target or with the phases of the business cycle; see Bec *et al.* (2000) and Dolado *et al.* (2000). Such asymmetry not only renders inadequate any linear equation for the monetary variable(s), but also supports the view that different types of nonlinearity should be permitted in the various equations of the VAR. From an empirical perspective, Anderson and Vahid (2001) find nonlinearity in both equations of their bivariate system for output growth and the interest rate spread, but the hypothesis of common nonlinearity is soundly rejected.

Specifying and estimating a nonlinear VAR model to capture the full output/monetary policy interactions is a desirable objective of UK research, and this paper is a contribution towards that goal. In particular, this paper analyses the output equation, focusing on the output/interest rate relationship. Inflation is not included so that we may focus on the effects of interest rates for the real economy, but it needs to be recognised that any relationship uncovered reflects not only the direct effects of interest rates on output, but also indirect effects which operate through inflation or other omitted variables. We are alert to the fact that the use of an interest rate "rule" by the monetary authority may imply that current and projected future output plays a role in the setting of interest rates. To alleviate the resulting endogeneity, the first lag of interest rate changes is excluded from all models estimated.

As the above discussion indicates, there is substantial evidence of asymmetry in the effect of interest rates (or other variables measuring monetary conditions) on growth, but the literature is not yet clear whether the asymmetry is associated with phases of the business cycle, with regimes in the monetary variable, or both. The two types of regime are, of course, closely related, both because monetary policy tends to be easier during recessions than expansions and because monetary conditions may contribute to regime changes in real activity. Nevertheless, understanding the relative contributions of the two is important for the monetary authority in assessing the impact of its policy.

Studies that explicitly compare regimes associated with monetary variables and real output apparently relate only to the US. Of these, Anderson and Vahid (2001) and Rothman *et al.* (2001) find that the nonlinearity is associated with the monetary variable, whereas Weise (1999) concludes the opposite. While there are important differences between the approaches of these studies, all three use the smooth transition class of nonlinear models. An alternative type of regime-dependent model is the Markov-switching model, associated with Hamilton (1989). Here we prefer the smooth transition class because we have found it to be relatively flexible while, in practice, simpler to estimate than the corresponding Markov switching model with regime probabilities that are functions of observed variables. This simplicity derives from the single transition function required to capture two regimes in the smooth transition case, compared to the two required in the Markov switching model. Related models of the latter type are employed in the UK analysis of Simpson *et al.* (2001).

Although following the recent literature in using smooth transition models to capture the nonlinearity in the output/interest rate relationship, we go further than previous studies in that we allow for two transition functions, one defined in terms of past output growth and the second in terms of interest rate changes. Hence, we are able to compare directly the implications of the two types of regimes. To give a preview of our results, we find that both types of regimes are important for understanding the impact of monetary policy on output growth in the UK.

The paper proceeds as follows. Section II explains the models used, with empirical results discussed in Section III. Section IV then contains an analysis of the implied dynamics and asymmetries in the estimated models, while Section V concludes.

II. Model Specification Issues

Smooth Transition Models

Smooth transition regression (STR) models are a development of the smooth transition autoregressive (STAR) models promoted by Teräsvirta and Anderson (1992) and Teräsvirta (1994). Öcal and Osborn (2000) explore some of the implications of univariate STAR models for the UK when the regimes can be associated with stages of the business cycle.

With a single transition function defined in terms of a transition variable r_{t-d}, our general STR model for the quarterly growth in real output (y_t) is

$$y_t = \phi_{00} + \sum_{i=1}^{8} \phi_{0i} y_{t-i} + \sum_{j=2}^{8} \delta_{0j} z_{t-j} + F(r_{t-d})[\phi_{10} + \sum_{i=1}^{8} \phi_{1i} y_{t-i} + \sum_{j=2}^{8} \delta_{1j} z_{t-j}] + \varepsilon_t \tag{1}$$

where z_t is the quarterly change in interest rates. Notice the exclusion of the first lag of interest rate changes in (1) as already discussed, and also the use of a maximum lag of 8 quarters for both y and z, since this lag is always able to account satisfactorily for the dynamics. The disturbance ε_t is assumed to be white noise with zero mean; in practice it is also assumed to be homoscedastic over regimes with variance σ^2 and to be normally distributed.

The transition function is assumed to have the logistic form

$$F(r_{t-d}) = \frac{1}{1+\exp\{-\gamma(r_{t-d} - c) / \hat{\sigma}(r)\}} \qquad \gamma > 0 \tag{2}$$

where $\hat{\sigma}(r)$ is the sample standard deviation of r. This logistic form has been widely used for STR models when the regimes are defined by “large” and “small” values of r_{t-d}. For example, using the change in the short-term interest rate as the transition variable with $c = 0$ allows output growth to be asymmetric with respect to increases and decreases in interest rates. In practice, however, we estimate the location parameter c and the slope parameter, γ, together with the delay d, of (2). As possible transition variables, we investigate both quarterly output growth and the quarterly change in interest rates, together with the corresponding annual change variables. This latter transformation effectively smoothes the changes and may be more appropriate for capturing “regimes” than the more noisy quarterly changes (see also van Dijk *et al.* 2002).

An obvious generalisation of (1) incorporates two transition functions, F_1 and F_2 to yield the general specification

$$y_t = \phi_{00} + \sum_{i=1}^{8} \phi_{0i} y_{t-i} + \sum_{j=2}^{8} \delta_{0j} z_{t-j} + F_1(y_{t-d})[\phi_{10} + \sum_{i=1}^{8} \phi_{1i} y_{t-i} + \sum_{j=2}^{8} \delta_{1j} z_{t-j}]$$
$$+ F_2(z_{t-e})[\phi_{20} + \sum_{i=1}^{8} \phi_{2i} y_{t-i} + \sum_{j=2}^{8} \delta_{2j} z_{t-j}] + \varepsilon_t \qquad (3)$$

where both $F_1(y_{t-d})$ and $F_2(z_{t-e})$ are logistic functions as in (2) and e is the delay of the second transition function. By using both y_{t-d} and z_{t-e} as transition variables in (3), we consider regimes defined in terms of both output growth and interest rate changes. It should be noted, however, that prior to estimating (3), we consider statistical tests of additional nonlinearity in the single transition function model of (1). Öcal and Osborn (2000) and van Dijk and Franses (1999) find two-transition function models to be of practical importance for modelling macroeconomic time series for the UK and US respectively as univariate series. However, such specifications do not appear to have been applied previously to examine the impact of monetary policy.

Modelling Procedure

To provide a basis of comparison for the STR models, linear models are also estimated. All linear and nonlinear models are initially specified with maximum lag orders of eight, with intermediate lags then deleted one by one (starting with the least statistically significant according to the *t*-ratio) provided that such deletions reduce the Akaike Information Criteria (AIC).

Our procedure for the specification and estimation of STR models is similar to that of the univariate study of Öcal and Osborn (2000), but relies more systematically on grid search procedures. For the specification of all single-transition STR models the procedure is:

1. Undertake a three-dimensional grid search of the residual sum of squares (RSS) over values for d (to a maximum of 8 lags), γ and c. Each grid search involves $\gamma = 1, 2, ..., 100$ and 40 values for c.[1] The range of γ is extended if a boundary value minimises the RSS.
2. The minimum RSS from step 1 provides values of γ, c and d for an initial estimate of the transition function. Conditional on this transition function, the general model of equation (1) is estimated by ordinary least squares (OLS) and AIC is used to select a specific dynamic specification (deleting the most statistically insignificant variable at each stage, provided this improves AIC).
3. Maximum likelihood estimation of the selected nonlinear model from step 2 is undertaken, including estimation of the parameters γ and c of the transition function. Further lags may be deleted at this stage if this improves AIC.[2]

Notice the use of a fixed transition function in step 2 above. This speeds model specification, since estimation can be conducted by OLS when the transition function is given. We have found this procedure to work well in practice for single transition models, typically resulting in very similar specifications and estimates to those obtained using a full nonlinear estimation after each variable deletion.[3]

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[1] Essentially, the observed series is ordered by value, extremes are ignored (by omitting the most extreme 15 values at each end) and 40 values are specified at equal intervals over the remaining range.

[2] Most estimation is undertaken in the package GAUSS. However, Vinod (2000) has questioned the numerical accuracy of the non-linear estimation routines in GAUSS. To avoid such problems our estimates are checked in RATS (Doan, 1995). We find the same parameter estimates but smaller standard errors for the estimation in Gauss with problematic models.

[3] Clearly, the validity of this procedure depends on the estimated transition function varying relatively little as lags are dropped from the model. Thus, a conservative variable deletion strategy needs to be employed.

For the two-transition function model, a further grid search (over $\gamma_1, c_1, \gamma_2, c_2$) is undertaken based on the delay parameters estimated from the single transition function models. Model specification and estimation then proceed as above. We investigated specifications obtained after a grid search also involving the delays *d* and *e*, but these did not lead to satisfactory models.[4]

Diagnostic tests are presented for our estimated models, with the results shown as *p*-values. Tests are performed for normality, ARCH effects, residual autocorrelation and additional nonlinearity. Both the ARCH and autocorrelation tests consider an order of 4 under the alternative hypothesis. For the STR models, the last two tests are performed as in Eitrheim and Teräsvirta (1996) for the specific model (ignoring "holes") with fewer lags. In the case of the linear model, the nonlinearity test suggested by Teräsvirta (1994) is applied to the linear model including all lags of GDP and interest rates to the maximum of 8. Because of degrees of freedom problems with an overall test statistic such as suggested by Luukkonen *et al.* (1988), nonlinearity tests are applied separately for each lag of the possible transition variable.

Two tests specific to STR models are presented. One is the general parameter constancy test of Eitrheim and Teräsvirta (1996). The second is a test for regime-dependent heteroscedasticity. The latter is computed by running a regression of the squared residuals on the value(s) of the transition function(s) and testing the null hypothesis of zero coefficient(s) on the transition function(s). This test is, strictly speaking, not valid in the sense that it assumes that the transition function is known, rather than estimated. Nevertheless, it should

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[4] Extensive grid searches were carried out, but the final model derived using the lowest RSS from the grid search was typically poor. This may be due to the large number of redundant parameters included in the general model of (3), so that the initial grid search does not give a reliable guide to the appropriate transition functions with two such functions. Full grid search results are available from the authors upon request.

give some indication of the validity of the assumption that the disturbance variance in (1) or (3) is constant.

Statistical comparison across linear and nonlinear specifications is not a straightforward issue and here we present two types of comparison. Firstly, values for the AIC and Schwarz Information Criteria (SIC) are presented. These are computed as $AIC = \ln(RSS/T) + 2k/T$ and $SIC = \ln(RSS/T) + k\ln(T)/T$, where k is the number of estimated parameters using T sample observations. In these computations, the delay(s) are not counted as parameters being estimated for the nonlinear specifications. As already discussed, AIC is used as the basis of the dynamic specification of each model. However, it should be emphasised that neither AIC nor SIC values can be validly compared across linear, one transition and two transition specifications, because the continuity assumptions on which such comparisons are based are not valid when comparing across different parametric families of models (Kapetanios, 1999). The usual measures R^2 and the residual standard deviation (s, corrected for degrees of freedom) are also presented.

The second statistical model comparison undertaken is an examination of the forecast accuracy of our models. One-step ahead forecast measures are presented for 1995q1 to 1999q1, with this providing a genuine post-sample comparison since these observations are not employed for model specification. The model is sequentially re-estimated (but not re-specified) each quarter throughout the forecast period. However, this period may not show the nonlinear models to advantage, since steady growth was observed throughout. For this reason we also generate one-step ahead forecasts between 1990q1 and 1999q1 to compare the models' capability for forecasting the 1990s recession. In this latter case, the comparison is not a genuine post-sample one, since the observations to 1994q4 are also used for model specification. Once again, however, the parameters are sequentially re-estimated over the period.

III. Estimated Models

Our focus of interest is the effect of interest rates on the quarterly growth rate of output. For the latter, we use seasonally adjusted real gross domestic product (GDP), where seasonally adjusted values have been used to avoid complications associated with seasonality. Figure 1[5] shows the values of GDP growth, obtained as the first difference of the (natural) logarithm of real GDP, over our sample period of 1960q1 to 1994q4. Outliers, evident in the original series as dotted lines in this figure, have been removed by linear interpolation in the levels series[6]. The treatment of outliers is an important practical problem in nonlinear economic modelling (see van Dijk *et al.*, 1999), but since they are not of central interest to this study, we choose to remove them.

The monetary policy variable is the change in the interest rate on three-month prime bank bills, with this series being an average of daily short-term interest rates. The change, rather than the level, of the nominal rate of interest is used because this variable is stationary according to conventional unit root tests. Quarterly and annual changes in nominal interest rates are used, both of which are shown in Figure 1. Our estimated linear and nonlinear models are reported in Table 1.

Single-Transition Function Models

As anticipated, interest rate changes have negative effects on GDP growth. These effects are evident primarily at lags of one to two years in the linear model of Table 1. However, the evidence of ARCH effects in this model and, more particularly, the nonlinearity tests for Model 1 (see Tables 2 and 3) indicate that this linear specification may not be adequate.

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[5] All the graphics in the paper were created in Givewin (Doornik and Hendry, 2001).

There is strong evidence in Table 2 of nonlinearity when the transition variable is quarterly GDP growth lagged three periods, with evidence also at other lags. The test rejection here is stronger than when the lagged annual GDP difference is used as a transition variable in Table 3. Nevertheless, Table 3 does indicate possible nonlinearity associated with regimes in interest rates when annual changes of that variable are used at a lag of 4 or 7 quarters.

A grid search examined over GDP and interest rates as possible transition variables, with annual and first differences considered for both variables, points to the third lag of quarterly GDP growth as the transition variable (grid search results for each possible transition variable are given in the appendix tables). Since the nonlinearity test and grid search results point to the same transition variable, this is selected as one candidate. The resulting nonlinear model is shown as the GDP regime model, namely Model 2, in Table 1.

This GDP regime model has an estimated location parameter of $\hat{c}_1 = 0.0129$, so the transition function comes into effect only when past growth has been relatively high. Therefore, these are not business cycle regimes in the sense of expansions and contractions, but rather high growth versus normal growth or decline. The negative estimated coefficients for the interactions between the regime (represented by F_1) and the interest rate lags imply that interest rate changes have stronger negative effects in the high growth regime than otherwise.

Our specification search leading to the GDP regime model also considered the possibility that the transition variable could relate to interest rate changes. However, had we considered only interest rates, then the nonlinearity test results (Tables 2 and 3) and the grid search (see the appendix tables) would both point to the fourth lag of the annual interest rate change. The resulting interest rate regime model is shown as Model 3 in Table 1. To keep

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[6] These were removed where the value of the quarterly difference exceeded three standard deviations from its mean. The outliers removed correspond to 1963q1, 1973q1 and 1979q2.

the separation clear between the GDP and interest rate regimes, the transition function in this second case is denoted as F_2.

The estimated location parameter for the interest rate transition function, at 2.89 percentage points, implies that only large interest rate increases over a year lead to nonlinear effects on GDP growth a year later. Therefore, once again the regimes detected are not connected with the sign of the transition variable, but rather with relatively extreme values. Also notice from Table 1 how the estimated coefficients that arise from the interaction of this transition function and lagged interest rates are negative. The obvious implication is that a large interest rate increase will have a larger (negative) effect than a decrease in interest rates of the same magnitude. However, this comment needs to be qualified by the complicated effects which work through the GDP dynamics and through the shift in the intercept implied by positive coefficient estimated for the transition function variable itself, F_2. The interpretation of these effects will be investigated further by the generalised impulse response function analysis in Section IV.

The transition function F_2 is plotted against time as the first chart in Figure 3, with shading indicating the recessions as dated by Birchenhall, Osborn and Sensier (2001). Indeed, this plot indicates the difficulty in separating business cycle regimes from those associated with monetary variables, since the interest rate transition function picks up the first two indicated recessions very well. Further, the spike in 1986 can be associated with a low growth episode. However, interpreted as a recession indicator, the transition function is too early for the 1990s recession.

This paper set out to examine the relative importance of monetary and business cycle regimes for the effect of interest rates on GDP. Since the specification search over both past GDP growth and interest rate changes selected lagged GDP growth as the transition variable, it appears that business cycle regimes (or, to be more precise, high growth versus normal growth or decline) are a more important source of nonlinearity than interest rate regimes. Nevertheless, comparing the two single transition function models of Table 1, there is little basis to discriminate statistically between them. They have similar fit, as measured by the residual standard error(*s*), by R^2 or by the model selection criteria of AIC and SIC. The diagnostic tests of both are generally satisfactory, although the interest rate regime model gives evidence of heteroscedasticity across regimes.

Other results, however, indicate that neither type of regime fully captures the nonlinearity. In particular, the tests for additional nonlinearity in Tables 2 and 3 show some evidence of nonlinearity associated with the annual interest rate change lagged six or seven quarters for the GDP regime model, while the interest rate regime model has some suggestion of nonlinearity associated with the third lag of quarterly GDP growth. Therefore, there may be roles for both GDP and interest rate regimes.

The Two-Transition Model

The last column in Table 1 (denoted Model 4) presents a model combining both types of regimes. That is, it includes two transition functions, one defined in terms of GDP growth lagged three quarters and the other using the annual difference of interest rates lagged seven quarters. The specification of this model was based on the nonlinearity test results in Table 2 and 3, since the lowest *p*-value is obtained when $\Delta_4 IR_{t-7}$ is examined as an additional transition variable in the GDP regime model.

The transition function F_1 again relates to GDP regimes. Compared to the earlier GDP regime model, the estimated value for the scale parameter γ_1 and, more particularly, the location parameter c_1 is seen to be largely unaffected by the introduction of the transition function for interest rate regimes. Analogous comments apply to the transition function F_2, despite the use of lag 7 rather than lag 4 of annual interest rate changes as the transition variable. The transition functions for this final model of Table 1 are plotted as functions of observed values of the corresponding variables in the two panels of Figure 2 and against time in the last two panels of Figure 3. It is notable that the interest rate transition function F_2 now fits quite well with the 1990s recession as dated by Birchenhall *et al.* (2001).

Although the estimated transition functions alter relatively little in the two-transition model of Table 1 compared with the two single-transition models, the coefficients are sometimes quite sensitive to the specification. One notable change is that the effect of F_2 on the intercept is positive in the single transition function model, but negative (indeed significantly so) when the GDP regime function F_1 is included.

The interactions of both regime indicators with the interest rate changes are generally negative in the two-transition function model. This implies that compared with "normal", there are two distinctive situations in which interest rate changes have increased negative effects on GDP. These are when past quarterly GDP growth has exceeded (approximately) 1.25 percent or where interest rates have increased by more than 2.4 percentage points over a year.

The diagnostics of the two-transition model in Table 1 are generally satisfactory, despite some evidence of heteroscedasticity associated with the regimes. Tables 2 and 3 yield no evidence of unmodelled nonlinearity for this specification.

Little has been said about the estimated coefficients on the autoregressive lags in these models. Interpretation is, clearly, not simple. However, one feature is that, despite the use of seasonally adjusted GDP data, the one and/or two year lag of GDP growth is always significant in the models of Table 1 and, further, these coefficients vary with regime. This indicates scope for further exploration of the relationship between nonlinearity and seasonality for GDP.

Forecast Comparisons

As noted earlier, we consider one-step ahead forecast comparisons over 1995q1-1999q1 and 1990q1-1999q1, with the former being a post-sample comparison. The forecast root-mean square error (RMSE) for each model over each of these periods is given in Table 4. For the latter period, we further break down the RMSE for quarters of recession (1990q3-1992q2) and expansion (the remaining quarters of this period).

Table 4 indicates that nonlinear models may, but certainly do not necessarily, improve the accuracy of output forecasts according to the RMSE criterion. For the post-sample period, 1995q1-1999q1, the most accurate forecasts are provided by the linear model. The single-transition model based on interest rate regimes is the worst in forecasting over this period by a substantial margin. Although this post-sample forecast comparison is of limited usefulness because it covers only business cycle expansion observations, the very poor performance of the interest rate regime model here points to it being an inadequate representation of the GDP/interest rate relationship.

The relative performances of the models change when the forecast period is extended to include the 1990 recession. The model with the best RMSE over this longer period is the two-transition function model. In particular, over the recession period itself, this model does particularly well in relation to its competitors. This is presumably due to the interest rate transition function here predicting the recession, as illustrated in Figure 3. On the other hand, the linear model has the lowest RMSE for the 1990s expansion, which concurs with the result over the post-sample period, which is also a period of expansion. The results overall echo those found in other recent studies of the forecasting performance of linear and nonlinear economic models, including Simpson *et al.* (2001).

IV. Dynamic Properties

Figures 4 and 5 illustrate the properties of our models through a counter-factual analysis based on the generalised impulse response functions (GIRF) of Koop *et al.* (1996). The linear model is included for comparison purposes, although the effects for this model are independent of the timing of the shock, with magnitudes of effects proportional to the size of the shock. All effects are multiplied by 100 and then cumulated to have the interpretation as percentage effects on the level of real GDP.

We examine the dynamics of GDP for our estimated models by applying a disturbance shock of magnitude $\pm 2s$ at a specific quarter, where s is the estimated standard error of the residuals from the corresponding model. Shocks applied in all subsequent quarters are randomly generated NID(0, s^2) variables, with the new log level of GDP calculated from the simulated data, then averaged over simulations. The comparison baseline simulation uses the same procedure, but NID(0, s^2) shocks throughout. The effect of the shock is then the average log GDP from the shocked simulations less that from the baseline simulations.

Figure 4 provides a comparison of the impact of these shocks in times of expansion and recession. For GDP during the 1980s expansion we simulate the GIRF using actual GDP data prior to 1987q4 and the actual interest rate data of the time period. In 1987q4 the output growth variable had an observed value of 0.0105, corresponding to F_1 (after a delay of three quarters) being relatively small, but either positive shock at 1987q4 affects the value of the regime indicator F_1. The second period is the recession quarter 1991q2, when observed growth implies $F_1 = 0$ and the shocks have little or no effect on F_1. Again these simulations use actual GDP data prior to the period of the shock (1991q2) and actual interest rate data throughout.

Disturbance shocks have distinct effects in the models. The linear model and the single-transition model based on interest rate regimes (Model 3) imply similar effects, with the impulse response functions increasing in magnitude to around 3 percent after 15 quarters with symmetric effects. The responses in the two models with GDP regimes are similar to each other, although larger in magnitude for the expansion shock effect in the case of the two-transition specification. For these two models, however, the effect of the shock can change depending on the regime. An asymmetry is apparent when positive shocks have subsequent negative effects on GDP for the expansion period, but such shocks have positive effects when applied during recession. Negative shocks in times of expansion in the two-transition model lead to an increase in output after three years, with this higher level then maintained throughout the simulated period.

Figure 5 again presents the simulated effect on the log level of GDP but this time after shocks are applied to the level of the interest rate in times of expansion and recession. The magnitude of the change is ± 0.75 percentage points which is applied to the actual level of the interest rate series in the quarter at the start of the simulation period. A new interest rate series is then simulated by applying ± 0.75 change (as appropriate) for each of eight quarters, and then no change for the last eight quarters of the period. This allows 5 quarters of annual interest rate changes of 3 percent that will trigger the interest rate transition function in two of the models. The baseline model used for comparison has no interest rate changes for the whole period. The same expansion and recession periods are used as in the disturbance simulations of Figure 4.

Interest rate changes in Figure 5 are symmetric and have the same effect between expansion and recession for the linear model, reductions in the interest rate increase output and increases lead to falls in GDP. All nonlinear models show time-dependence in the influence of the interest rates. A slight asymmetry can be detected in the single-transition model with GDP regimes since interest rate changes in expansions have effects of greater magnitude than in recessions, but overall they are similar to the linear model.

Greater asymmetry is detected in the models that include the interest rate transition functions. The chart for Model 3 implies that increases in the interest rate during an expansion will actually lead to an increase in GDP after eight quarters when the transition function becomes active. An effect of a smaller magnitude is also felt in recession though the increase starts later, after 10 quarters. Reduction of the interest rate in both phases has the effect of increasing output after a year, but these effects are relatively small in magnitude. This would suggest to policy makers that using the interest rate to kick-start an economy in a recession is of little use as suggested by Johnson (1962). However, the implication of this model that large interest rate increases lead to higher output is implausible from an economic perspective. These results could be related to the “price puzzle” in the monetary policy VAR literature for the US (see for example Sims, 1992) where, contrary to what is expected, estimated models can imply that increases in interest rates lead to increases in inflation and output. Walsh (1998) explains that the reason for this puzzle may be because the variables included in the VAR do not span the full information set available to the central bank. They will increase interest rates because their forecasts of future inflation are high but the factors that have led to these higher forecasts may already be in play and impossible to offset. An increase in output may then accompany this increase in inflation. Our estimated relationship for the interest rate regime model may be detecting a corresponding omitted variable effect. However, these results do point to misspecification of this model, especially when considered in conjunction with its poor post-sample forecast performance as discussed above.

The response of Model 4 with the GDP and interest rate transition function is quite different to that just discussed for increases in interest rates. Here increases of the interest rate in expansion lead to flat output for seven quarters then a large drop, similar to the finding of Thoma (1994) that negative monetary shocks have greater effects in periods of high growth. Our final model suggests that a reduction in the interest rate in a recession could lead to a greater increase in GDP as compared to when the same reduction is applied in an expansion. Therefore monetary policy is more effective in a recession, supporting Garcia and Schaller (1995). There are also asymmetries in relation to the sign of the interest rate changes, with interest rate increases having effects of greater magnitude than decreases as suggested by Cover (1992) and Karras (1996).

V. Concluding Remarks

The motivation for this paper was to examine possible asymmetric effects for changes in nominal interest rates on growth in UK real GDP. In particular, we wished to examine possible nonlinearities concerned with the stages of the business cycle and with interest rate regimes, in order to shed light on the question of the underlying nature of asymmetries.

Our results strongly suggest that the stage of the business cycle is important, with interest rates having a greater influence on output when past growth has been high than when past growth has been "normal" or negative. This is the case whether business cycle regimes are considered alone, or in conjunction with interest rate regimes. However, in the absence business cycle regimes, an interest rate regime model yields poor post-sample forecasts and implausible economic implications. Assuming that the results obtained here are not specific to the UK experience, this indicates that studies that consider only monetary policy regimes may be seriously misspecified. Since this statement covers a large body of literature, including Choi (1999), Cover (1992), DeLong and Summers (1988), Karras (1996), Morgan (1993) and Ravn and Sola (1996), it is important that further research examines the relative roles of these two types of regimes in the context of other countries, particularly the US.

Despite the greater importance of the business cycle regime, we do find evidence that monetary policy regimes have a distinct role in a two transition function specification that allows for both types of regime. Therefore, we conclude that asymmetries may operate in relation to both the business cycle and monetary regimes. Monetary policy contractions (increasing the interest rate) appears to reduce output in both cycle phases, but more so for expansion, whereas monetary expansions at a gradual pace do lead to increases in output of a steady amount. This would suggest the Bank of England is correct in carefully manoeuvring the interest rate by small amounts when there is a looming danger of economic crisis.

This paper takes a relatively simple approach by focusing only on the effect of interest rates on output growth. To further enhance the understanding of monetary policy effects over the business cycle, there is scope for more nonlinear analysis into the interactions of the inflation rate with output growth and with the application of monetary policy by the Central Bank. Another area for further investigation is the possibility that the variances may be time varying. Some of our results suggest that the disturbance variance may change with the regime, especially with the monetary policy regime. Also recent US evidence in McConnell and Perez Quiros (2000) points to the importance of changing volatility over time for capturing business cycle regimes. We hope to tackle some of these issues in our future research.

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Table 1: Estimated Models

	Model 1: Linear Model	**Model 2: GDP Regimes**	**Model 3: Interest Rate Regimes**	**Model 4: GDP & Interest Rate Regimes**
Transition Variable(s)		**ΔGDP_3**	**Δ_4IR_4**	**ΔGDP_3 & Δ_4IR_7**
Constant	0.0038 (3.86)	0.0038 (3.94)	0.0060 (6.93)	0.0047 (5.21)
ΔGDP_2		-0.1389 (-1.95)		
ΔGDP_4	0.2188 (2.74)	0.3524 (5.42)	0.3446 (4.40)	0.3850 (5.31)
ΔGDP_6	0.1302 (1.64)	0.1403 (1.93)		
ΔGDP_8			-0.2215 (-3.19)	
ΔIR_2	-0.0011 (-1.63)			-0.0012 (-2.19)
ΔIR_3				0.0017 (2.67)
ΔIR_4	-0.0017 (-2.47)	-0.0016 (-2.81)	-0.0013 (-1.96)	-0.0014 (-2.35)
ΔIR_5	-0.0018 (-2.55)	-0.0015 (-2.58)		
ΔIR_7	-0.0016 (-2.42)			0.0013 (1.92)
ΔIR_8		-0.0011 (-1.66)		
F_1		0.0302 (3.85)		0.0392 (4.79)
F_1*ΔGDP_2				-0.4263 (-2.35)
F_1*ΔGDP_3		-1.247 (-3.24)		-1.783 (-4.38)
F_1*ΔGDP_4		-0.6675 (-9.54)		-0.8437 (-4.96)
F_1*ΔGDP_5				-0.4043 (-2.79)
F_1*ΔGDP_6		-0.3956 (-2.41)		
F_1*ΔGDP_8		-0.4295 (-2.97)		
F_1*ΔIR_2		-0.0043 (-2.91)		
F_1*ΔIR_4				0.0027 (1.65)
F_1*ΔIR_7		-0.0087 (-4.34)		-0.0148 (-6.72)
F_1*ΔIR_8		-0.0028 (-1.61)		-0.0038 (-2.29)
γ_1		13.1 (657.9)		9.854 (2.74)
c_1		0.0129 (27.67)		0.01345 (24.17)
F_2			0.02605 (3.40)	-0.0054 (-2.80)
F_2*ΔGDP_1			0.4925 (3.02)	0.5330 (4.09)
F_2*ΔGDP_2				-0.3420 (-2.77)
F_2*ΔGDP_4			-0.9879 (-5.56)	
F_2*ΔGDP_5			1.566 (6.23)	
F_2*ΔGDP_6			-0.5984 (-2.34)	
F_2*ΔGDP_8			0.5235 (2.44)	-0.2896 (-2.12)
F_2*ΔIR_2			-0.0070 (-3.98)	
F_2*ΔIR_3				-0.0046 (-3.19)
F_2*ΔIR_4			-0.0170 (-5.37)	
F_2*ΔIR_5			-0.0107 (-4.74)	
F_1*ΔIR_7			-0.0033 (-1.71)	
γ_2			235.1 (0.09)	225.1 (0.03)
c_2			2.887 (13.79)	2.405 (9.74)
SIC/AIC	-9.305/-9.455	-9.363/-9.727	-9.383/-9.725	-9.427/-9.919
s/R^2	0.008407 /0.1742	0.007287 /0.4571	0.007316 /0.4481	0.006500 /0.5898
Normality	0.089	0.772	0.251	0.072
ARCH	0.020	0.815	0.529	0.741
Autocorr.	0.387	0.455	0.880	0.597
Parameter Constancy		0.946	0.833	0.994
Regime Heteroscedasticity		0.093	0.019	0.043

Note: Estimated coefficients are presented with *t*-statistics in parenthesis. Diagnostic tests are presented as *p*-values.

Table 2: Tests for Nonlinearity using First Difference Transition Variables

Transition Variable	Model 1: Linear Model	Model 2: GDP Regimes	Model 3:Interest Rate Regimes	Model 4:GDP & Interest Rate Regimes
ΔGDP_1	0.013	0.112	0.869	0.902
ΔGDP_2	0.079	0.174	0.583	0.339
ΔGDP_3	0.000	0.190	0.051	0.093
ΔGDP_4	0.004	0.383	0.678	0.764
ΔGDP_5	0.004	0.490	0.615	0.843
ΔGDP_6	0.150	0.720	0.752	0.394
ΔGDP_7	0.026	0.077	0.453	0.451
ΔGDP_8	0.032	0.698	0.397	0.886
ΔIR_2	0.052	0.776	0.385	0.885
ΔIR_3	0.085	0.051	0.914	0.460
ΔIR_4	0.426	0.884	0.976	0.964
ΔIR_5	0.583	0.714	0.850	0.868
ΔIR_6	0.067	0.663	0.713	0.673
ΔIR_7	0.092	0.194	0.602	0.502
ΔIR_8	0.356	0.270	0.243	0.908

Notes: The nonlinearity test for the linear model is that suggested by Teräsvirta (1994) and for the STR models is that detailed in Eitrheim and Teräsvirta (1996). The *p*-value is presented for a test for nonlinearity or additional nonlinearity for each possible transition variable.

Table 3: Tests for Nonlinearity using Annual Difference Transition Variables

Transition Variable	Model 1: Linear Model	Model 2: GDP Regimes	Model 3:Interest Rate Regimes	Model 4:GDP & Interest Rate Regimes
Δ_4GDP_1	0.224	0.640	0.864	0.412
Δ_4GDP_2	0.002	0.299	0.920	0.948
Δ_4GDP_3	0.009	0.244	0.567	0.575
Δ_4GDP_4	0.020	0.547	0.915	0.726
Δ_4GDP_5	0.204	0.748	0.929	0.941
Δ_4GDP_6	0.300	0.489	0.812	0.884
Δ_4GDP_7	0.282	0.638	0.362	0.977
Δ_4GDP_8	0.595	0.310	0.517	0.742
Δ_4IR_2	0.311	0.590	0.880	0.680
Δ_4IR_3	0.103	0.674	0.698	0.782
Δ_4IR_4	0.009	0.053	0.423	0.499
Δ_4IR_5	0.117	0.080	0.247	0.738
Δ_4IR_6	0.139	0.023	0.147	0.243
Δ_4IR_7	0.002	0.012	0.114	0.352
Δ_4IR_8	0.155	0.668	0.833	0.931

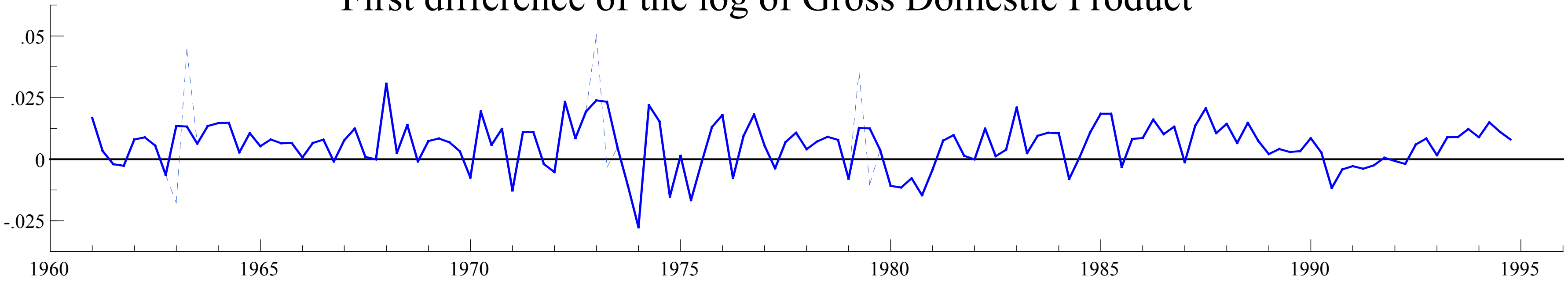
Notes: See Table 2.

Table 4: Forecast Root Mean Square Errors

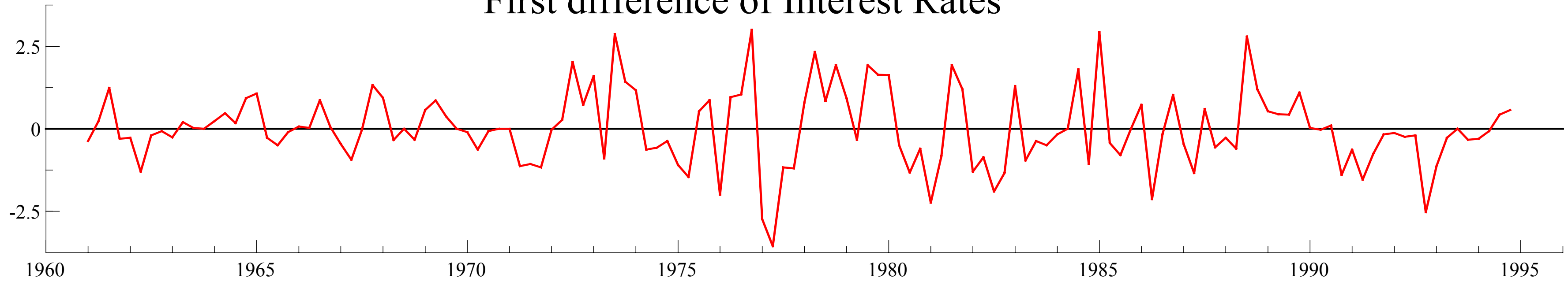
Period	Model 1: Linear Model	Model 2: GDP Regimes	Model 3: Interest Rate Regimes	Model 4: GDP & Interest Rate Regimes
1995q1-1999q1	0.3267	0.3640	2.6052	0.3745
1990q1-1999q1	0.4896	0.4918	0.4943	0.4633
1990s Recession	0.8513	0.8151	0.8168	0.5054
1990s Expansion	0.3148	0.3424	0.3456	0.4362

Note: RMSEs are multiplied by 100 for ease of comparison.

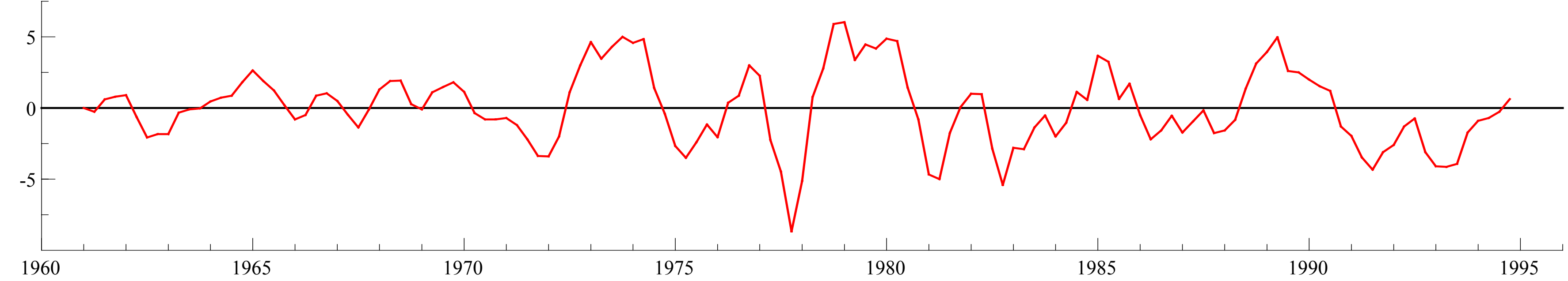
Figure 1: Data



First difference of the log of Gross Domestic Product



First difference of Interest Rates



Annual difference of Interest Rates

Figure 2: Transition Function for Two-Transition Model

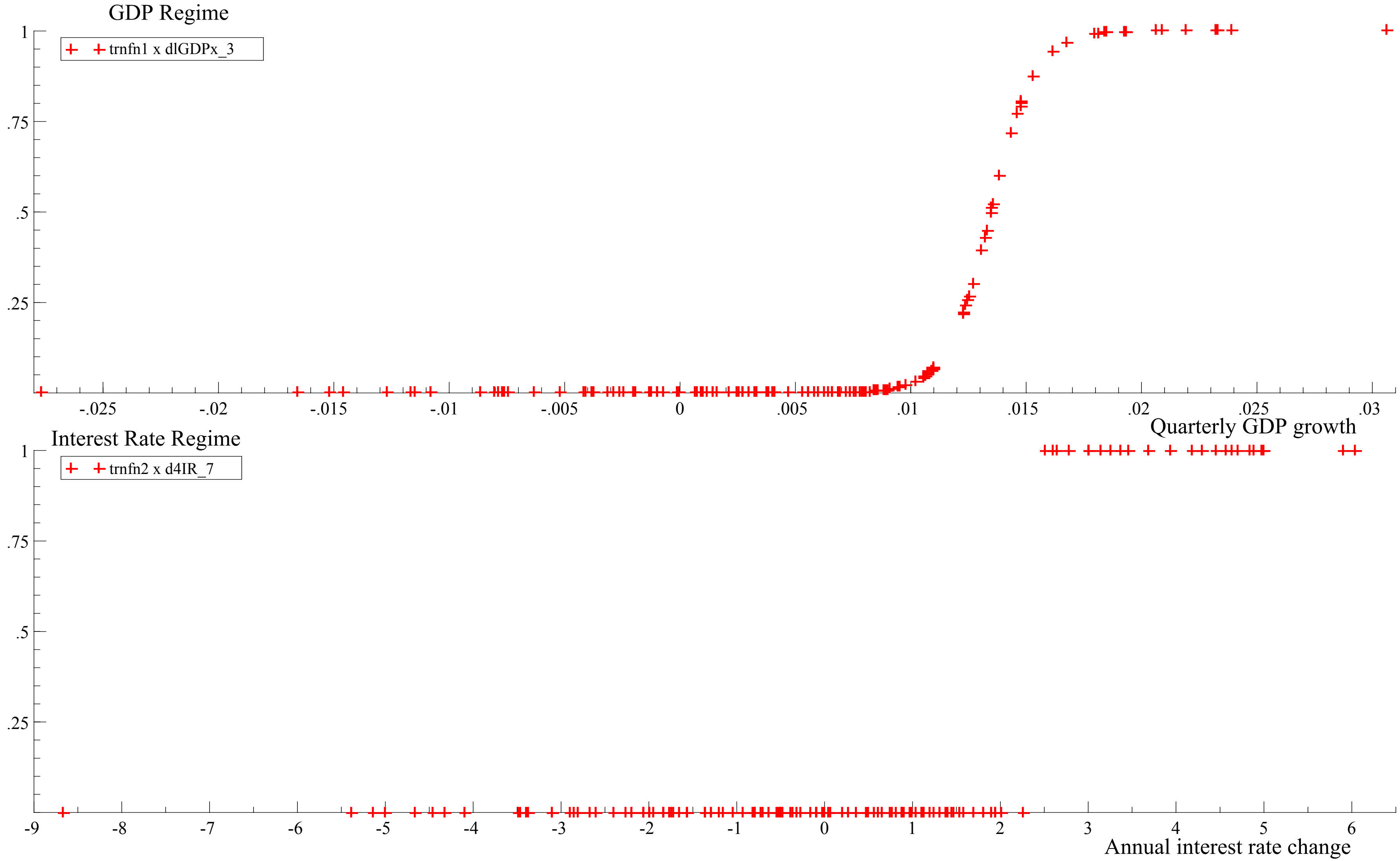


Figure 3: Transition Functions over Time (recessions shaded)

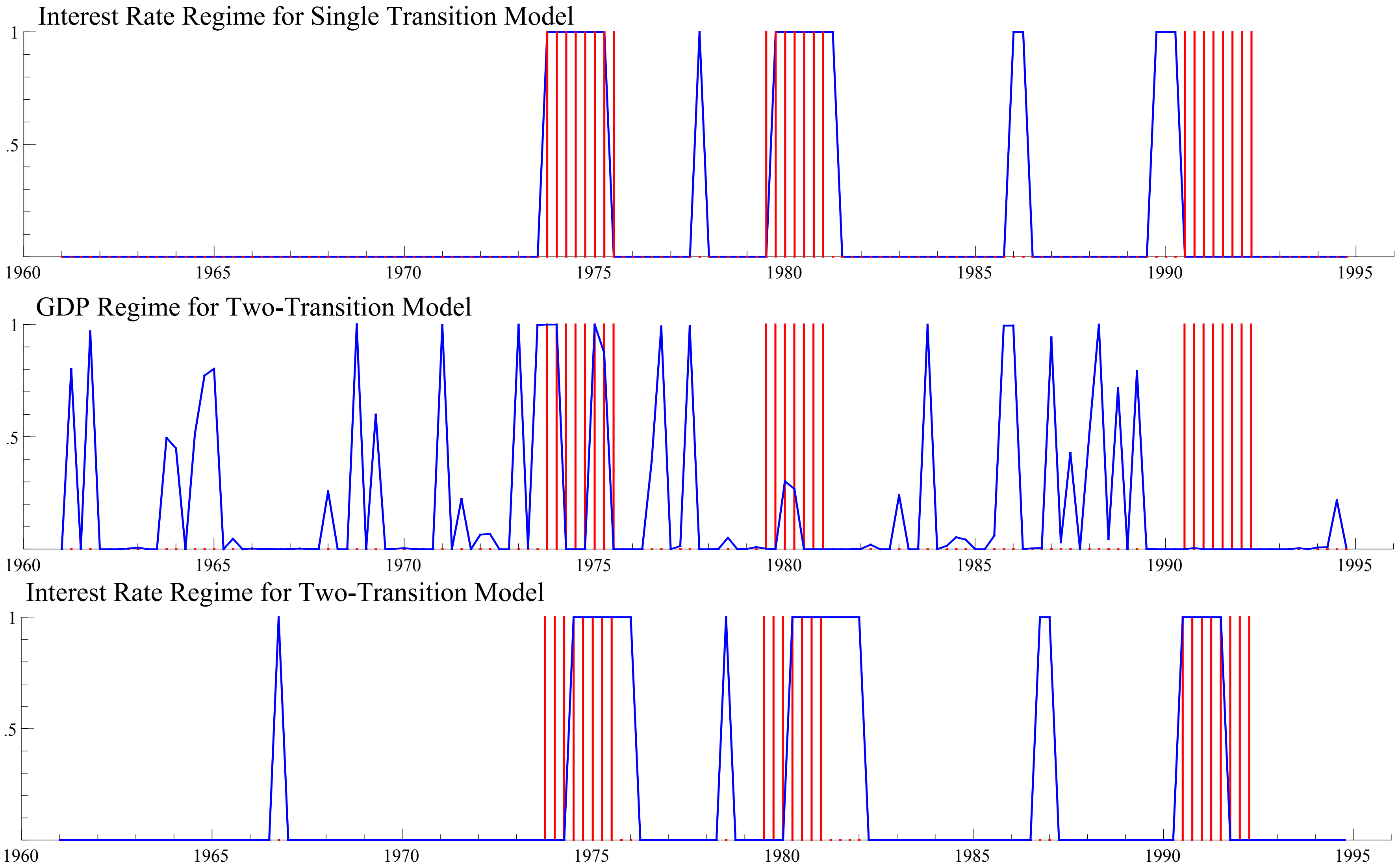
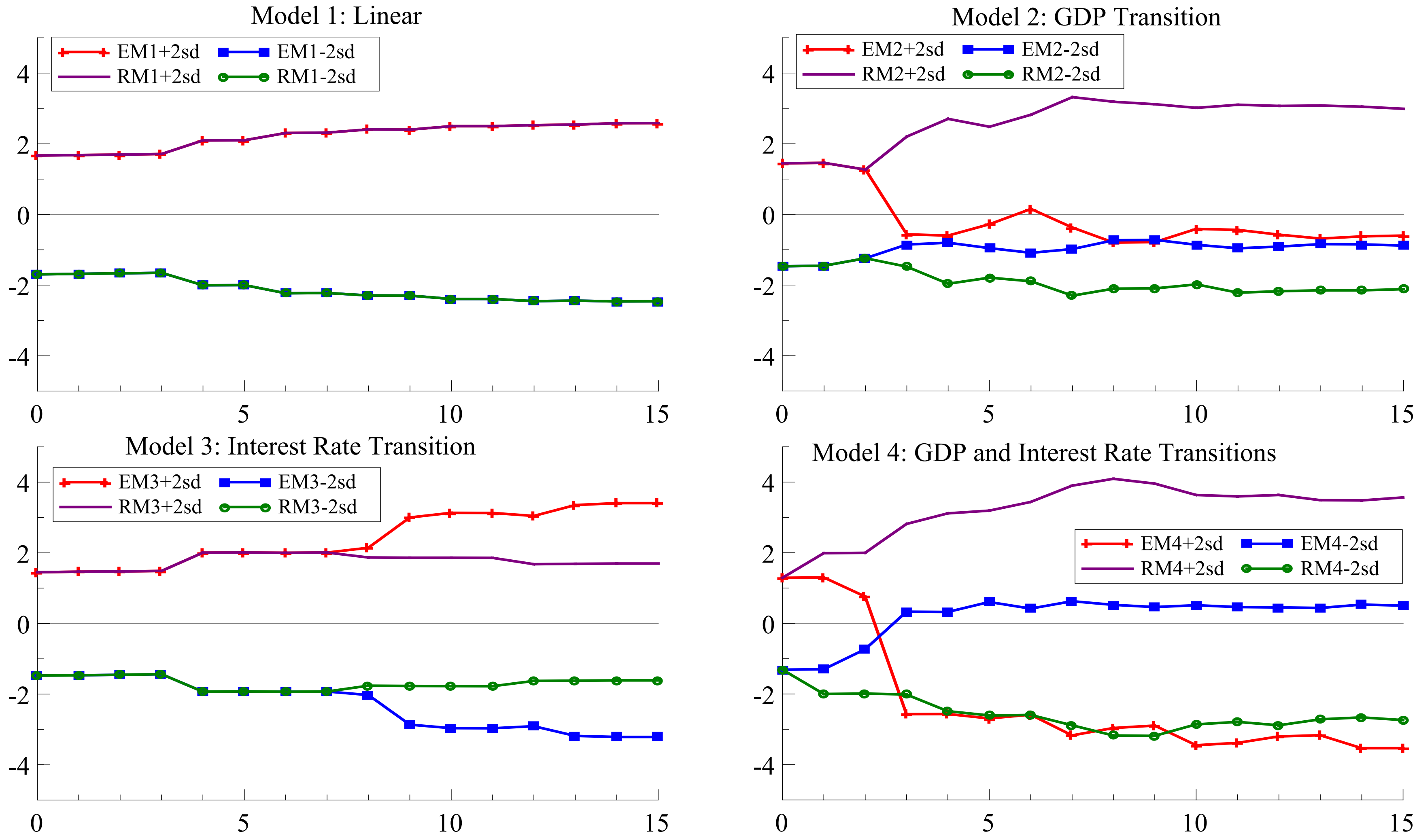
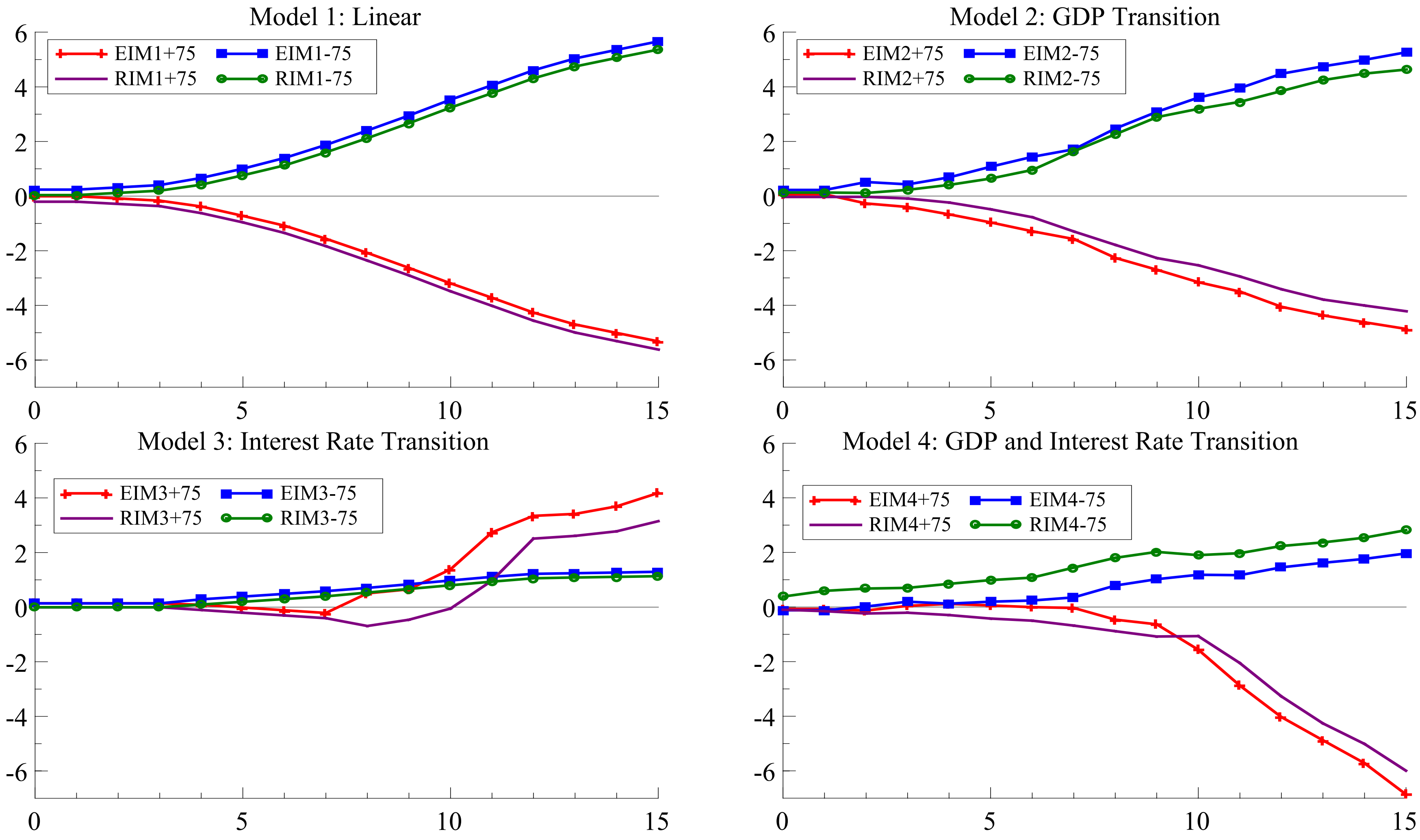


Figure 4: Effect of Disturbance Shock in Expansion and Recession



Notes: All are cumulated GDP growth. Key to legend: E – expansion phase simulation from 1987q4; R – recession phase simulation from 1991q2.

Figure 5: Effects of Interest Rate Changes in Expansion and Recession



Notes: See Figure 4.

APPENDIX

Grid Search Results for Specification of Single-Transition Models

Table A.1: Grid Search for First Difference Transition Variable

Delay	γ	*c*	**RSS**
ΔGDP_3	13	0.01313	0.005884
ΔGDP_1	62	-0.003162	0.005934
ΔIR_6	1	1.238	0.006312
ΔIR_7	100	-0.5125	0.006445
ΔGDP_4	100	0.01555	0.006452
ΔGDP_8	100	0.01126	0.006473
ΔGDP_5	100	0.01040	0.006603
ΔIR_2	100	1.238	0.006646
ΔGDP_7	100	0.003979	0.006889
ΔIR_5	100	1.113	0.006912
ΔIR_3	48	-0.8250	0.006921
ΔIR_8	100	-0.8250	0.007018
ΔIR_4	71	-0.3758	0.007069
ΔGDP_2	100	0.003503	0.007133
ΔGDP_6	39	0.01732	0.007260

Notes: Selected γ and *c* variables shown at each lag length with the minimum Residual Sum of Squares (RSS).

Table A.2: Grid Search for Annual Difference Transition Variable

Delay	γ	*c*	**RSS**
Δ_4IR_4	150	2.723	0.005974
Δ_4IR_5	19	3.047	0.006268
Δ_4GDP_2	2	0.04447	0.006312
Δ_4IR_3	150	2.400	0.006408
Δ_4GDP_3	1	0.04473	0.006430
Δ_4IR_7	150	-1.926	0.006457
Δ_4GDP_1	150	0.02182	0.006532
Δ_4IR_8	55	-2.860	0.006569
Δ_4IR_2	150	3.208	0.006572
Δ_4GDP_4	150	0.04483	0.006749
Δ_4IR_6	93	-2.116	0.006877
Δ_4GDP_5	100	0.03985	0.006976
Δ_4GDP_8	150	0.02715	0.007005
Δ_4GDP_6	150	0.03985	0.007055
Δ_4GDP_7	84	0.02334	0.007252

Notes: See Table A.1.