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Abstract

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The relevance of international spillovers and asymmetric effects in the Taylor rule

by

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1 Introduction

Since the 1980s central banks switched to policies based on rules, with strong emphasis on price stability. The Taylor rule has become popular to describe the monetary policy stance in both advanced and developing countries (Taylor, 1993). It links policy interest rates to deviations of inflation from its target and real output from its potential. According to the Taylor principle, the central bank should raise the nominal interest rate by more than one percentage point for each one percent increase in inflation. Taylor (1993) emphasized the importance of rule-like behavior on part of central banks as a key framework to ensure time-consistency, monetary transparency, and independence.

While policy rates have been broadly in line with the Taylor rule during the Great Moderation, they have been persistently moving below it in both advanced and developing countries since the turn of the century. The monetary accommodation implied by this deviation has been blamed as a potential factor in the build-up of imbalances in the period before the financial crisis (Kahn, 2010). Therefore, the explanation of the deviations is of high academic and policy relevance.

A straightforward extension of the traditional Taylor rule is based on the idea of accounting for international spillovers. There are several reasons why international linkages have become increasingly important. On the one hand, declining real interest rates may have introduced an upward bias in the Taylor rule, i.e. an overestimation of the Tylor rate.[2] Capital inflows from emerging markets to the industrial countries might have led to lower real interest rates, as stated by the savings glut hypothesis (Bernanke, 2005). Underdeveloped financial markets in the emerging countries restricted the ability of their citizens to borrow against future income and redirected their savings to industrial countries, in particular to the US. Asset shortages triggered a reduction of the equilibrium real interest rates at a global scale (Caballero, Fahri and Gourin-

[2] In other words, the estimated Taylor rule shows inadequately high interest rates.

chas, 2008). This development might also reflect secular demographic trends in the industrial countries, specifically strong asset demand exerted by the baby boomer generation. A further explanation refers to an increase in the perceived riskiness of capital assets in the wake of asset price booms and busts after the turn of the century. Therefore, policy interest rates fell below the Taylor rule levels in close synchronization across countries. For example, Hofmann and Bogdanova (2012) have argued that deviations from the Taylor rule can be best interpreted as a change in the global equilibrium real interest rate.

A further transmission channel for international spillovers stems from the fact that central banks no longer decide on policy rates in an independent way (Taylor, 2013). While interest rates have been set according to national conditions up to the turn of the century, policy reactions have been increasingly affected by the international environment since then. Hence, the deviations might indicate a substantial shift in the monetary policy regime. Among others, Kim (2000) demonstrated that US monetary policy shocks can affect other countries. Belke and Gros (2005) provided evidence that the ECB followed the Fed in their interest rate decisions. In fact, low US interest rates can increase risk taking in other countries, and one option to react is to lower foreign interest rates, see Bruno and Shin (2012). In addition, central banks tend to resist large exchange rate appreciations, and adjust their interest rates according to the behavior of other central banks. Most importantly, the actions of the Federal Reserve Bank have been magnified due to the mimicking responses of other central banks (Gray, 2012). Overall, deviations from a Taylor rule can amplify due to international spillovers (Taylor, 2013).

Deviations can also occur due to asymmetric behavior by the central banks. For example, interest rate setting rules can be different in expansionary and restrictive periods of monetary policy. This distinction may hold independently of an impact of international spillovers. Asymmetric adjustment leads to nonlinear Taylor rules as recently proposed by Riedl and Brüggemann (2011), among others. Such explanations might be better able to capture the actual evolution of policy rates. For example, expansionary and contractionary monetary decisions might be based on a different set of determinants. In this vein, Alcidi et al. (2009) show that linear Taylor rules fail to detect relevant policy decisions driven by policy-makers' judgment while smooth transition models are well-suited to improve linear Taylor rule functions.

This paper examines the causes for the deviations from the standard Taylor rule by analyzing the importance of both international spillovers and nonlinearities for monetary policy decisions in the main industrial countries, i.e. the US, the Euro Area (Germany), the UK and Japan. A simple linear benchmark model is selected as a point of departure and extended step by step. After incorporating international spillovers via foreign interest rates, nonlinear dynamics are examined through a smooth transition approach. Several variables steering the transition between the regimes are considered, such as increasing and decreasing interest rates, the output gap, oil prices and lagged differentials between domestic and foreign interest rates. Overall, our empirical results suggest that both incorporating international spillovers and allowing for nonlinear dynamics is important to increase the usefulness of the Taylor rule to explain actual monetary policy behavior. International spillovers seem to be more important in periods of increasing interest rates, with the exception of the euro area. This appears consistent with recent evidence by the IMF in its spillover reports in the context of the envisaged Fed's exit from unconventional monetary policies (IMF, 2013).

The remainder of the paper is organized as follows. The next section (Section 2) reviews the Taylor rule. Section 3 discussed its extension by international spillovers, but also documents the deviations from linear specifications. In Section 4 nonlinear specifications are presented. Section 5 holds the empirical results. Finally, Section 6 concludes with some policy implications.

2 Deviations from the Taylor rule

The Taylor rule establishes a linear relationship between the nominal interest rate, inflation and the output gap. In its *standard* form

(1) $$i_t = r^* + \pi^* + \alpha_1(\pi_t - \pi^*) + \alpha_2 y_t + \varepsilon_t$$

i is the nominal policy determined interest rate, r^* is the long-run equilibrium real interest rate, π^* stands for the central bank's inflation objective, π represents the actual inflation rate, and *y* is the output gap, i.e. the deviation of actual and potential output, expressed as a percentage of the latter. The error ε fulfills the white noise properties and the index *t* denotes time. The parameters describe how strongly the policy interest rate should respond to deviations of inflation from its target and of output from its potential. The Taylor rule implies that central banks aim at stabilizing inflation around its target and output around its potential. Positive (negative) deviations of the two variables from these levels would be associated with a tightening (loosening) of the monetary policy stance. An inflation reaction coefficient (α_1) above one ensures that real interest rates respond to inflationary pressures (Taylor, 1993, 1998). In that case an increase in inflation triggers a rise in the real interest rate.

Central banks often prefer to adjust policy rates not instantaneously, but gradually with small, distinct steps in a particular direction. If they partially adjust towards desired levels, *interest rate smoothing* can be incorporated through the inclusion of the lagged policy rate (Judd and Rudebusch, 1998).

(2) $$i_t = \rho i_{t-1} + (1-\rho)(r^* + \pi^* + \alpha_1(\pi_t - \pi^*) + \alpha_2 y_t) + \varepsilon_t$$

The higher the weight of the lagged policy rate, the slower is the adjustment to intended interest rate levels[3]. The lagged interest rate could be also seen as a proxy of further determinants of the policy rate which are less important and excluded from the specification. Equations (1) and (2) are *ex post* specifications of the Taylor rule, i.e. setting of interest rates is conditional to contemporaneous inflation values and the output gap. If monetary policy acts with a delay of *k* periods, a forward looking (ex ante) specification

[3] In contrast, nominal interest rates have been cut aggressively towards the zero lower bound during the global financial crisis to avoid output losses, especially after the Lehman collapse, see Gerlach and Lewis (2011).

(3) $$i_t = \rho i_{t-1} + (1-\rho)(r^* + \pi^* + \alpha_1(E_t\pi_{t+k} - \pi^*) + \alpha_2 E_t y_{t+k}) + \varepsilon_t$$

may be more appropriate, where *E* denotes the rational expectations operator (Clarida, Galí and Gertler, 2000). Nominal interest rates depend on their past levels, the expected deviations of inflation from its target and output from its long run potential. Expectations exploit all information available at time when the prediction is made. Nominal interest rates fluctuate around a constant equilibrium level, the latter defined as the sum of the real interest rate and the inflation target. It should be noted, that the Taylor rule acts as a rule of thumb and leaves out many factors that might be actually relevant for monetary policy, for example, the risk that the policy rate hits the zero lower bound.

Many empirical studies demonstrated that monetary policy of advanced countries can, to a lesser or larger extent, be explained by this kind of reaction function. Despite of the persistence of policy rates, the reaction coefficient of the inflation gap tends to be larger than unity and to exceed the coefficient of the output gap, especially in more recent periods of monetary history. Moreover, forward-looking models seem to fit the actual behavior of central banks slightly better than contemporaneous versions. For example, Orphanides (2001, 2003) used real-time instead of ex-post revised data. As the main interest in the relevance of international spillovers and nonlinearities, a distinction between real time and revised estimates is less important in this paper, as these issues are relevant in both datasets.

Since the turn of the century, however, deviations of actual policy rates from the Taylor rule increased. In particular, actual nominal interest rates fell persistently below the levels implied by the Taylor rule, suggesting a loose stance of monetary policy in the period before the financial crisis. According to Clarida (2012), the differences turn out to be slightly smaller if ex ante rates are considered. The deviations might have been caused by the omission of explanatory factors, such as international spillovers and asymmetric policy responses (Taylor, 2013). Note in this context that an exclusion of relevant variables might erroneously be interpreted as a change in the reaction coefficients with regard to the other variables, i.e. inflation and the output gap.

3 Linear specifications of Taylor rules

Quarterly data are obtained from the OECD Main Economic indicators and cover the 1982:1 to 2008:4 sample period. In contrast to, for instance, Belke and Klose (2013), we stop our analysis at that date because our aim is to consider the period of conventional monetary policy. The starting point of our analysis is motivated by the end of the so-called pseudo monetarism policy period of the Federal Reserve (Timberlake, 1993). As said, we exclude the developments during the recent financial crisis as the main interest is in the deviations from the rule prior to the crisis. Three months interbank interest rates are used. Inflation is measured as the percentage of the quarter-on-quarter change of prices inflation, i.e. 100*log(p_t/p_{t-1}), where p denotes the consumer price index. Potential output is obtained by the HP Filter (lambda = 1600) applied to real GDP. The output gap is then determined by the difference between actual and potential GDP, expressed as a percentage of the latter. An output gap beyond (below) 100 percent thus indicates excess (under-) utilization of capacity. The analysis is conducted for the US, the euro area, the UK and Japan. As the euro area series do notstart before 1999, German data is used instead in the previous period and the series is in the following denoted as "euro area" data. As a starting point, the linear Taylor rule is estimated via OLS as a benchmark. To account for partial adjustment and serial correlation, the first two lagged interest changes are also included (Table 1).

-Table 1 and Figure 1 about here-

The estimated coefficients are in line with theoretical predictions. Nonetheless, the output gap coefficient can be frequently considered as insignificant due to high standard errors. The inspection of the deviations from the respective country-specific rules shows that the Taylor principle is a reasonable approximation of monetary policy until the turn of the century (Figure 1). Outliers during the 1990s might be explained by particular events such as the start of the deflationary period in Japan. However, the limitations of the standard model became more pronounced since then. Therefore, explicitly taking into account international spillovers and asymmetric adjustment of central banks might be envisaged to capture the actual monetary policy behavior.

To control for international spillovers, we extend the Taylor reaction function by the foreign interest rate. The latter is proxied by the US rate for the euro area, the UK and Japan. For the US, we employ a linear combination of interest rates in the euro area, UK and Japan. The weights used for this purpose reflect the relevance of the respective currencies in the international reserves held by the US. It should be noted that the evidence exhibited in Table 2 is robust to this choice.

Table 2 and Figure 2 about here

Compared to the standard model, the coefficients of inflation and output remain largely unchanged except for the ”euro area” where the output gap becomes significant, but with a wrong sign. The foreign interest rate is highly relevant for each economy, except of the US where the coefficient is significant but of small size. Hence, the US monetary policy might matter for other countries, but not vice versa. Although the deviations from the rule displayed in Figure 2 have declined, they are still pronounced in the extended model. Therefore, the inclusion of international spillovers is not sufficient by itself to solve the puzzle and nonlinear dynamics are considered as a next step in that direction.

4 Nonlinear specifications of Taylor rules

4.1 Exponential and logistic smooth transition models

Smooth regression models suggested by Teräsvirta (1994, 1998) provide a convenient framework to capture nonlinear dynamics in the Taylor rule (Alcidi et al, 2009; Brüggemann and Riedel, 2012). Compared to specifications with discrete structural breaks, the models allow for gradual change between two regimes. In the extended Taylor rule equation

(4)

$$i_{t=}[\alpha_1 + \beta_1(y_t) + \beta_2(\pi_t - \pi_t^*) + \beta_3(i_{t-1}^*)] + [\beta_1{}'(y_t) + \beta_2{}'(\pi_t - \pi_t^*) + \beta_3{}'(i_{t-1}^*)]F(z_t, \gamma, c) + u_{t+k},$$

$F(z_t, \gamma, c)$ is a transition function which ascertains the speed of adjustment between the regimes and can have either a logistic or an exponential shape. The coefficients α_1 and β_i correspond to the lower regime, and $(\alpha_1 + \alpha_1{}')$ and $(\beta_i + \beta_i{}')$ to the upper regime (van Dijk et al., 2002). An exponential and a logistic transition function are close substitutes and relate to different patterns of nonlinearity. A logistic transition allows for different parameters above and below a threshold, while an exponential transition accounts for a distinction between small and large deviations from a threshold. The choice between the alternatives can be made according to economic arguments. For example, if the aim is to distinguish between regimes of increasing and decreasing interest rates, a logistic transition could be adopted. Brüggemann and Riedl (2011) and Alcidi (2009) have provided evidence that the logistic smooth transition approach is a viable alternative to linear reaction functions for the analysis of monetary policy. However, exponential specifications might be preferred if the transition between the regimes relies on some kind of interest rate differential.

To explain the underlying dynamics, consider the case where $F(z_t, \gamma, c)$ is a continuous *logistic* transition function bounded between 0 and 1:

(5) $$F(z_t, \gamma, c) = [1 + \exp(-\gamma(z_t - c)/\sigma_{zt})]^{-1} \quad \text{with } \gamma > 0.$$

It implies that the lower (upper) regime is associated with negative (positive) values of the transition variable z_t relative to the location parameter c. The logistic function rises monotonically from 0 to 1 as the transition variable increases, i.e. $F(z_t, \gamma, c) \to 0$ as $z_t \to -\infty$ and $F(z_t, \gamma, c) \to 1$ as $z_t \to +\infty$, while it is equal to 0.5 if $z_t = c$. The location parameter can be interpreted as a threshold dividing equation (4) into three different extreme regimes corresponding to $\lim_{z_t \to -\infty} F(z_t, \gamma, c)$, $\lim_{z_t \to +\infty} F(z_t, \gamma, c)$ and $z_t = c$. In the case of $z_t = c$, equation (4) reduces to the linear model (3), where $\alpha = \alpha_1 + 0.5\alpha_2$ and $\beta = \beta_i + 0.5\beta_i{}'$. Moreover, the smoothness parameter γ controls the speed of transition between the extreme regimes (Baillie and Kilic, 2006).

The second possibility we consider for some specifications corresponds to $F(z_t, \gamma, c)$ as a bounded continuous *exponential* transition function which lies between 0 and 1 and thus has the following functional form:

$$F(z_t, \gamma, c) = 1 - \exp(-\gamma(z_t - c)^2/\sigma_{zt}) \text{ with } \gamma > 0, \tag{6}$$

where z_t indicates the transition variable, σ_{zt} represents its standard deviation, γ denotes a slope parameter and c is a location parameter. The transition function given by Equation (6) is symmetrically U-shaped as $F(z_t, \gamma, c) \to 1$ for $z_t \to \pm\infty$ and $F(z_t, \gamma, c) \to 0$ for $z_t = c$, so that an adjustment for deviations of the transition variable z_t above and below the location parameter c, which can be interpreted as a threshold value, is symmetric, as opposed to the logistic case mentioned below. The slope parameter γ determines the speed of the transition between the extreme regimes, with lower absolute values implying slower transition.

4.2 Choice of the transition variable

By modelling the dynamics in a nonlinear form, transition variables need to be specified in advance. As the results might depend on this selection, different transition variables should be considered to assess the robustness of the results. A straightforward choice is the *lagged change of the interest rate* compared to a threshold *c* which is restricted to be zero. In this case, the different regimes correspond to periods of declining or rising interest rates, i.e. to different stances of the business cycle and/or different stances of monetary policy (negative change for expansionary and positive change for contractionary policy). In addition, the lagged *output gap* is selected to control for the possibility that monetary policy might be influenced by different phases of the business cycle. To account for possible determinants related to international spill-overs and the uncovered interest rate parity (UIP), the *lagged differential between the domestic and the foreign interest rate* is considered. In this case we take into account that central banks (such as the ECB most recently) may be interested in exchange rate stabilization by setting their policy rates. Finally, lagged *oil price changes* might – according to the savings glut hypothesis - steer the transition between the regimes (Belke and Gros, 2014). Revenues of oil exporters increase for example in case of rising oil prices. The recycling of petrodollars by purchases of US Bonds might drive US and worldwide interest rates down, resulting in international monetary policy coordination.[4] We consider all choices of transition variables at this stage.

5 Empirical results

To establish the presence of nonlinear effects in the Taylor rule we conduct a Lagrange multiplier test (Luukonen et al, 1988). Under the null hypothesis a linear model is assumed. If the linear specification in terms of the transition variable

$$(6)\quad \Delta i_{t+k} = \varphi_0 + \varphi_1(c_t) + \varphi_2(c_t)z_t + \varphi_3(c_t){z_t}^2 + \varphi_4(c_t){z_t}^3 + \epsilon_{t+k}$$

is valid, the coefficients φ_i should be equal to 0 for i=2,3,4. Linearity is rejected if at least φ_i is different from 0 implying that the higher order terms are significant. The test statistic is distributed as Chi-squared with 3 degrees of freedom. Our findings for the two Taylor-rule specifications, excluding or including foreign interest rates, are shown in Tables 3 and 4.

Tables 3 and 4 about here

The *linear* specifications are *rejected* if lagged interest rate changes, the interest rate differential and oil price changes are chosen as transition variables. Note that these results are obtained for

[4] We employ lagged realisations of the transition variables because in case of contemporary realisations the central bank would not be able to react to, for instance, change in oil prices in the same period.

both specifications in most of the cases. Hence, we can conclude that spillovers are important, regardless of the question whether international spillovers are included. Since nonlinear effects are, however, less visible for the output gap if the foreign interest rate is included (Table 4), the output gap is no longer considered as a potential transition variable from this stage. We have gained substantial evidence of non-linearity, because linearity has been rejected. The "true" transition variable is not known; the output gap is, however, not suitable for that. Overall, non-linear effects are important to explain monetary policy behavior for all economies.

The nonlinear findings for the three transition variables (the lagged change of the interest rate, the lagged differential between the domestic and the foreign interest rate, and the lagged oil price changes) based on nonlinear least squares (NLS) are reported in Tables 5 to 7. Note that we pre-select a logistic transition function for each transition variable except for the interest rate differential where an exponential function is chosen. With bigger interest rate differentials in-fluence carry trades and Japan's interest differential has been negative since the 90s.[5] As could be expected from the results from our nonlinearity tests (which reject the linear form), the Tay-lor coefficients frequently differ between the regimes. Overall, Figure 3 reveals that the inclu-sion of international spillovers and, even more, nonlinear dynamics improves the explanatory power of the standard Taylor reaction function. This can be seen by smaller deviations of the interest rates from the Taylor rates - in comparison with Figures 1 and 2 which include negative trend which seems to be eliminated in Figure 3. .

Tables 5 to 7 and Figure 3 about here

We now elaborate on the results for the different specifications with respect to the choice of the transition variable (3 cases). We start with the case of lagged *interest rate changes as the transi-tion variable* (case 1) so that the first regime corresponds to decreasing interest rates while the second corresponds to increasing interest rates.

[5] However, our estimations of the logistic specification are available on request as well.

Let us now turn first to the first regime of decreasing interest rates. The results show that the output gap is positively signed for the US and the UK in periods of decreasing interest rates (coefficient β1 in Table 5, 3rd column).[6] While the output gap is not significant for Japan, a negative impact of this variable turns out for the euro area, which is striking.

The inflation coefficient β2 turns out to be significant and positive for the UK, the euro area and Japan, but insignificant for the US (Table 5, 5th column).

The coefficient β3 of the lagged foreign interest rate is estimated to have a positive sign and turns out to be significant in all cases except for the euro area (Table 5, 7th column).

More or less, the signs of the estimated parameters are in line with theoretical predictions except for the case of the euro area. The results imply that the Fed, and the Bank of England are guided by business cycle considerations even if the interest rates have decreased over the previous quarter.

In a regime of increasing interest rates (β1+β1', Table 5, 3rd plus 4th column), the importance of the output gap becomes negative for the UK and the US while the variable is still not important for Japan. An interesting result is that the output gap coefficient for the euro area turns out to be positive now, as expected from theory.

For Japan, the euro area and the UK, the lagged US interest rate becomes increasingly significant (β3+β3', Table 5, 7th and 8th column) while no difference can be observed for the US.

Overall, these findings show that periods of decreasing interest rates are more influenced by output developments, except in the euro area, while the importance of international spillovers increases in periods of rising interest rates. The pattern that the monetary policy reaction in the euro area is only linked to domestic developments in times of increasing interesting rates might be traced back to the period after the German unification when the Bundesbank raised interest

[6] Note again that, according to eq. (4), the total effect is β1 + β1'.

rates to fight inflationary pressure as a result of accelerating capacity rates. As outlined above, the Bundesbank was a leading example for monetary policy guided by price stability within the sample until 1999.

Overall, we find that *coordination of monetary policy is less pronounced in case of decreasing interest rates*. Although the post-Lehman period is not included within our sample, this result may be promising with respect to the problem policymakers are currently facing when it comes to a coordinated exit from a policy of near zero interest rates.

Turning to the *oil prices as the transition variable* (case 2), we now distinguish between decreasing and increasing oil prices (Table 6). In case of decreasing oil prices, the inflation coefficient turns out to be significant for all economies (β2, Table 6, 5th column). Inflation becomes less important for the US and more important for Japan in case of positive oil price changes (ß2+β2', Table 6, 5th plus 6th column). For the euro area the inflation impact stays positive. As before, the importance of foreign interest rates increases in periods of rising oil prices for the US, Japan and the euro area (ß3 plus β3', Table 6, 7th and 8th column). The increasing coordination might be a result of decreasing US interest rates as a result of capital inflows from oil exporting economies, leading to foreign expansionary monetary policy to prevent capital inflows. The impact of the foreign interest rate for the UK is the same in both regimes.

Finally, we turn to case 3 in which the *lagged interest rate differential* is chosen as the *transition variable* (Table 7). Since we rely on an *exponential* function, the first regime corresponds to a small interest rate differential relative to the US while the second corresponds to a large interest rate differential. For the UK, the coefficients for the output gap and inflation are well signed for a small interest rate differential (β1 and β2, Table 7, 3rd and 5th column). However, large interest rate differentials are associated with wrongly signed coefficients (ß1 plus β1' and ß2 plus β2', Table 7, 4th and 6th column). A similar pattern can be observed for the inflation coefficient of Japan. However, the output gap coefficient of Japan is correctly signed for a large interest rate differential (ß1 plus ß1’, Table 7, columns 3 and 4), it is wrongly signed for a small interest rate differential (β1, Table 7, 3rd column). In addition, international interest rate spillovers appear to be stronger for a large interest rate differential in case of Japan (ß3 plus β3’,Table 7, 7th and 8th column). Interestingly, the picture for the euro area is different (Table 7, 4th row): a negative coefficient for the output gap and an insignificant inflation coefficient are observed in case of small interest rate differentials (β1 and β2). Large interest rate differentials lead to a positive inflation coefficient (ß2 plus ß2’) while the importance of the US interest rate decreases (β3 plus β3’). In general, US monetary policy shows less evidence of regime switches (Table 7, 2nd row). The only coefficient which changes is the impact of the output gap when large interest rate differentials are considered.

6 Conclusion

This study has allowed for various *nonlinear adjustment* patterns and *international spillovers* when analyzing monetary policy decisions against the background of the Taylor rule. Both effects are well-suited to model central bank behavior. Our approach fits the data reasonably well and reduces deviations compared to a standard Taylor rules. We identify several cases where Taylor rule coefficients change their sign between the regimes, suggesting that capturing nonlinear dynamics is quite important. It is also worthwhile mentioning that the magnitude of spillover effects is always positive and frequently larger compared to output gap and inflation as traditional determinants.

From a general point of view, our findings suggest that nonlinear patterns in central bank behavior can be due to several aspects. On the one hand, coefficients of the Taylor rule are different for expansionary and contradictory periods. In general, lagged changes of US interest rates are even more significant in times of increasing domestic interest rates. Hence, expansionary monetary policy decisions by the other central bank under observation have been more frequently related to changes in the US monetary policy stance. International spillovers resulting from interest rate differentials and different oil price pattern also introduce fluctuations in the Taylor reaction function coefficients. In contrast, the output gap turns out to be a less important determinant to capture nonlinear dynamics.

Overall, we confirm the main argument of Taylor (2013) that international coordination has become a more important aspect of monetary policy. Our results show that the Taylor rule framework turns out to be a useful framework for the assessment of monetary policy even after the millennium once nonlinear dynamics and international spillovers are included. Future research beyond the Taylor rule framework should for example be able to shed some light on the issue of policy coordination in a zero interest rate environment.

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Tables

Table 1 :Linear Estimations

	Constant	Gap	$INFG$	ΔI_{t-1}	ΔI_{t-2}
US	3.983*** [10.979]	0.087 [0.460]	1.323*** [5.901]	-0.309 [-0.851]	-0.346 [-0.794]
UK	5.824*** [27.830]	0.063 [0.365]	1.206*** [10.229]	0.220 [0.805]	0.119 [0.496]
Japan	4.767*** [14.912]	0.080 [0.774]	1.761*** [12.297]	-0.561 [-1.208]	-0.388 [-0.838]
Germany	2.601 [6.745]	-0.043 [-0.29854]	0.807 [2.549]	0.5780 [0.863]	0.5567 [0.876]

Note: * Statistical significance at the 10% level, ** at the 5% level, *** at the 1% level. T-values are given in parentheses.

Table 2: Linear Estimations including foreign interest rate

	Constant	Gap	$INFG$	ΔI_{t-1}	ΔI_{t-2}	if_{t-1}
US	4.455*** [13.026]	0.153 [0.798]	1.395*** [6.330]	-0.233 [-0.0756]	-0.315 [-0.816]	0.323*** [3.107]
UK	3.666*** [7.009]	0.158 [1.065]	0.751*** [7.935]	-0.014 [-0.056]	-0.134 [-0.627]	0.467*** [4.641]
Japan	1.227* [1.792]	0.175 [2.293]	1.124*** [5.987]	-0.978** [-2.529]	-0.818 [-2.148]	0.476*** [10.979]

Germany	2.373*** [4,675]	0.019 [0.197]	0.6634* [3.083]	0.5635 [1.429]	-0.3954 [-0.998]	0.368*** [3.931]

Note: * Statistical significance at the 10% level, ** at the 5% level, *** at the 1% level. T-values are given in parentheses.

Table 3: Teräsvirta test for nonlinearity excluding foreign interest rates

j	UK	US	Japan	Germany/Eurozone
$di(t-1)$	(0.000) **	(0.000) ***	(0.002) ***	(0.000) ***
$di(t-2)$	(0.003) ***	(0.000) ***	(0.000) ***	(0.046) ***
$gap(t-1)$	(0.031)**	(0.000) ***	(0.028) **	(0.000) ***
$gap(t-2)$	(0.009)***	(0.004) **	(0.084) *	(0.000) ***
$doil(t-1)$	(0.517)	(0.001) **	(0.008)***	(0.086) *
$doil(t-2)$	(0.192)	(0.014) **	(0.015) **	(0.288) ***
$id(t-1)$	(0.541)	(0.000) ***	(0.076) *	(0.002) ***
$id(t-2)$	(0.693)	(0.000) ***	(0.168)	(0.009) ***

Note: The table displays the p-Values of the LM test for nonlinearity as described in Section 3.3 for the lagged changes in interest rates, the lagged output gap, the lagged change in oil prices and the lagged interest rate differential. The test is distributed as χ^2 with three degrees of freedom. For details, see Teräsvirta (1998). */**/*** implies rejection of the null hypothesis at the 10/5/1% significance level

Table 4: Teräsvirta test for nonlinearity including foreign interest rates

j	UK	US	Japan	Germany/Eurozone
$di(t-1)$	(0.034) **	(0.000) ***	(0.001) ***	(0.007) ***
$di(t-2)$	(0.000) ***	(0.000) ***	(0.001) ***	(0.001) ***
$gap(t-1)$	(0.508)	(0.000) ***	(0.061) *	(0.386)
$gap(t-2)$	(0.678)	(0.000) ***	(0.031) ***	(0.087) *
$doil(t-1)$	(0.007) ***	(0.014) **	(0.076)*	(0.000) ***
$doil(t-2)$	(0.000) ***	(0.009) ***	(0.025) **	(0.000) ***
$id(t-1)$	(0.000) ***	(0.000) ***	(0.000) ***	(0.000) ***
$id(t-2)$	(0.000) ***	(0.000) ***	(0.000) ***	(0.000) ***

Note: The table displays the p-Values of the LM test for nonlinearity as described in Section 3.3 for the lagged changes in interest rates, the lagged output gap, the lagged change in oil prices and the lagged interest rate differential. The test is distributed as χ^2 with three degrees of freedom. For details, see Teräsvirta (1998). */**/*** implies rejection of the null hypothesis at the 10/5/1% significance level

Table 5: Nonlinear estimates based on lagged interest rate changes as transition variable

Country	α_0	α_1	β_1	$\beta_1{}'$	β_2	$\beta_2{}'$	β_3	$\beta_3{}'$	γ_1
UK	3.858*** [5.055]	-0.261 [-0.504]	0.506*** [3.759]	-0.577** [-2.556]	1.027*** [15.336]	-0.386 [-1.552]	0.257** [2.514]	0.361** [2.478]	3.014 [1.144]
US	0.372 [0.312]	1.237 [1.176]	0.411*** [0.637]	-0.712** [-1.275]	-0.513 [0.994]	-0.159 [-0.540]	0.513*** [2.790]	0.100 [0.835]	5.048 [1.489]
Japan	2.885*** [5.665]	-3.167*** [-4.127]	0.046 [0.485]	0.146 [1.466]	1.326*** [7.789]	-0.352 [-1.080]	0.330*** [6.945]	0.292*** [3.617]	46.656* [1.671]
Germa-ny/Eurozone	3.431*** [4.546]	-3.448*** [-5.468]	-0.181** [-2.154]	0.373*** [6.188]	0.633*** [5.070]	0.398* [1.947]	0.024 [0.419]	0.915*** [9.014]	1.490*** [2.935]

Note: * Statistical significance at the 10% level, ** at the 5% level, *** at the 1% level. The coefficients are estimated by nonlinear least squares. T-values are given in parentheses. Logistic specification of the transition function. Coefficients refer to eq. (4).

Table 6: Nonlinear estimates based on change of the oil price as transition variable

Country	α_0	α_1	β_1	$\beta_1{}'$	β_2	$\beta_2{}'$	β_3	$\beta_3{}'$	γ_1
UK	4.392*** [4.008]	-1.079 [-0.561]	0.959 [1.483]	-1.592 [-1.202]	0.746*** [9.264]	0.117 [0.565]	0.394** [2.449]	0.060 [0.210]	2.574 [0.953]
US	1.954*** [2.473]	-0.571 [-1.087]	0.332 [0.824]	-0.621* [1.966]	1.022** [3.547]	-0.675** [-4.245]	0.385*** [3.107]	0.106* [1.529]	74.012 [0.779]
Japan	2.026*** [3.924]	-0.708 [-1.381]	0.0514 [0.403]	0.138 [0.832]	1.0285*** [6.782]	0.337* [1.750]	0.3705*** [7.006]	0.146** [2.387]	19.848 [0.737]
Germa-ny/Eurozone	3.528*** [3.716]	-1.900*** [-5.173]	0.146*** [2.680]	-0.167 [-1.450]	0.724*** [4.502]	-0.164 [-0.808]	0.177 [1.645]	0.330*** [5.076]	20.561 [1.279]

Note: * Statistical significance at the 10% level, ** at the 5% level, *** at the 1% level. The coefficients are estimated by nonlinear least squares. T-values are given in parentheses. Logistic specification of the transition function. Coefficients refer to eq. (4).

Table 7: Nonlinear estimates based on the lagged interest rate differential as transition variable

Country	α_0	α_1	β_1	$\beta_1{}'$	β_2	$\beta_2{}'$	β_3	$\beta_3{}'$	γ_1
UK	1.567* [1.797]	3.557** [2.700]	0.147** [3.552]	-0.516** [-4.852]	0.353* [1.753]	-0.626** [-2.055]	0.743*** [5.197]	0.462 [1.588]	0.038*** [3.592]
US	-0.540*** [-3.411]	-6.785*** [-15.432]	-0.153*** [-3.707]	0.844*** [8.912]	0.333** [2.254]	-0.124 [-0.667]	1.012*** [32.698]	-0.028 [-0.482]	0.226*** [14.382]
Japan	0.869*** [2.240]	-9.118*** [-5.719]	-0.221** [-4.008]	0.405*** [3.497]	0.561*** [5.447]	-0.758*** [-3.326]	0.815*** [13.337]	0.261* [1.972]	0.001*** [5.370]
Germany/Eurozone	-0.307 [-0.752]	3.207*** [2.380]	-0.170*** [-4.306]	0.199 [1.426]	-0.088 [-0.539]	1.326*** [4.251]	1.068*** [13.334]	-0.860*** [-5.118]	0.994 [6.778]

Note: * Statistical significance at the 10% level, ** at the 5% level, *** at the 1% level. The coefficients are estimated by nonlinear least squares. T-values are given in parentheses. Exponential specification of the transition function. Coefficients refer to eq. (4).

Figures

Figure 1: Deviations from a linear Taylor rule

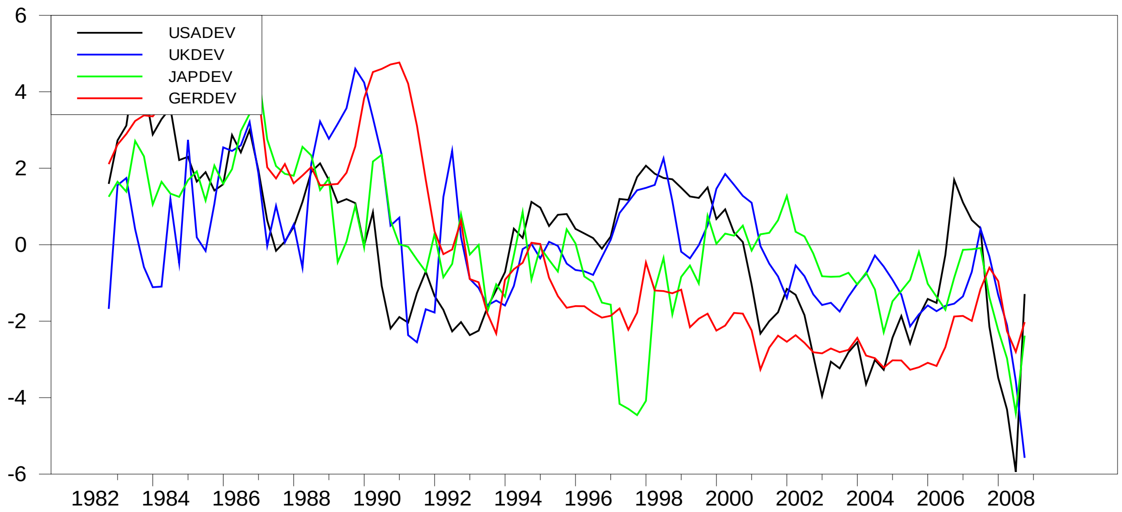

Figure 2: Deviations from a linear Taylor rule including the foreign interest rate

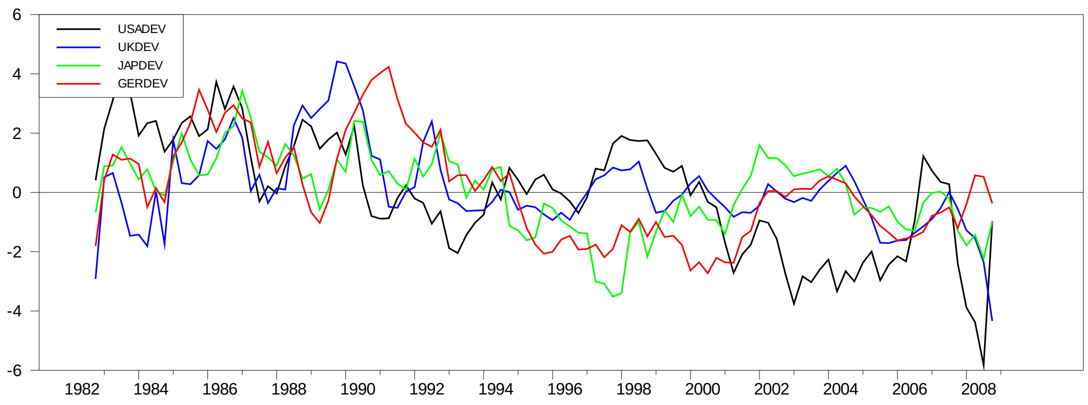

Figure 3: Deviations from a nonlinear Taylor rule including foreign interest rates based on interest rate changes as a transition variable