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by Tobias S. Blattner [2] and Emil Margaritov [3]

In 2010 all ECB publications feature a motif taken from the €500 banknote.

1 The views presented in this paper are those of the authors and do not necessarily reflect those of the European Central Bank. We would like to thank B. Hofmann and an anonymous referee for their comments and suggestions.

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Abstract

Estimations of simple monetary policy rules are often very rigid. Standard practice requires that a decision is made as to which indicators the central bank is assumed to respond to, ignoring the data-rich environment in which policy-makers typically form their decisions. However, the choice of the feedback variables in the estimations of simple rules bears non-trivial implications for the prescriptions borne from these rules. This paper addresses this issue for the euro area using a new comprehensive real-time database for the euro area and examines the ECB's past interest-rate setting behaviour in two complementary ways that are designed to deal with both model and data uncertainty. In a first step we follow the "thick-modelling" approach suggested by Granger and Jeon (2004) and estimate a series of 3,330 policy rules. In a second step we employ a factor-model approach similar to Bernanke and Boivin (2003) for the US Fed, but with structurally interpretable factors à la Belviso and Milani (2006). Taken together, we find a strong justification for the need of adopting robust approaches to describe the historical evolution of euro area monetary policy. We also find that the ECB is neither purely backward nor forward-looking, but reacts to a synthesis of the available information on the current and future state of the economy.

JEL classification: C50, E52, E58,
Keywords: Taylor rules; Monetary policy; Real-time data

I. Introduction

Since the seminal contribution by Taylor (1993), monetary policy rules have become a prominent feature in the academic literature. Taylor proposed a rule that depicts by how much a central bank should change the short-term interest rate to deviations of inflation and output from their target or potential levels. More generally, policy rules are understood as a positive or normative description of how a policy instrument, e.g. the short-term interest rate, the monetary base or the exchange rate, responds to changes in the macroeconomic environment. Such rules are often embedded as a closing condition in structural macroeconomic models resulting from the first order condition that solves the optimization problem relevant to the central bank (see, e.g. Clarida, Gali and Gertler 1999 for interest rate rules or Chowdhury and Schabert 2008 for monetary base rules) or are presented as single-equation reduced-form estimates in more empirically orientated work (see e.g. Clarida and Gertler 1996 or Orphanides 2001).

In practice, estimations of such rules are often plagued by a number of caveats and strong underlying assumptions. To begin with, researchers face the issue of *data uncertainty*. It is not at all clear whether the estimation of monetary policy rules using data that could not possibly be known to policy-makers at the time of the decision are informative for describing actual interest-rate setting. Data uncertainty can take two dimensions. The first relates to the *accuracy* of the data. Data are often preliminary and subject to sizeable and repetitive revisions over the course of time. In fact, it may take many years before data can be considered final. Past research suggests that the presence of noise in real-time estimates of inflation and the output gap must be accounted for in evaluating policy rules (see Orphanides 2001). Table 1 reveals the large differences that emerge from the use of real time or *ex post* data in past estimations of the ECB's monetary policy rule. The second dimension concerns the *timeliness* of data. This issue has largely been neglected in past research. Changes in the policy instrument are often linked to data that was not yet available to policy-makers at the time of the decision. For instance, interest-rate setting meetings in the euro area are usually held in the first week of each month. However, in estimating the ECB's reaction function it is common practice to link the interest-rate decision to data released during the course of the full month. Even under the assumption that the rule is correctly specified, reliance on possibly unknown data can prove misleading in identifying the historical pattern of monetary policy.

Table 1. Estimates of Taylor-type rules for the euro area [4]

Study	Data	Type	Inflation measure	Activity measure	Period	Inertia	Inflation weight	Output weight
Fourçans and Vranceanu (2004)	Ex post	FW (+4)	HICP	IP [1)]	01/99 - 10/03	0.84	2.80	0.19
Gerdesmeier and Roffia (2005)	Ex post	FW (+12)	HICP	ave [2)]	01/99 - 06/03	0.81	0.64	1.44
	Real time	FW (+12)	SPF	ave [2)]	01/99 - 06/03	0.98	2.13	1.63
	Real time	FW (+24)	SPF	ave [2)]	01/99 - 06/03	0.95	1.87	1.70
Sauer and Sturm (2007)	Ex post	FW (+3)	HICP	IP (GR)	01/99 - 03/03	0.91	1.02	0.47
	Ex post	FW (+3)	HICP	IP (HP)	01/99 - 03/03	0.88	0.86	0.86
	Real time	FW (+3)	HICP	IP (GR)	01/99 - 03/03	0.85	0.72	0.28
	Real time	FW (+3)	HICP	IP (HP)	01/99 - 03/03	0.92	2.31	2.35
	Survey	FW (+3)	ECON. [3)]	ESIN	01/99 - 03/03	0.84	1.88	0.44
Hayo and Hofmann (2006)	Ex post	FW (+12)	HICP	IP (LT)	01/99 - 05/04	0.85	1.48	0.60
Fourçans and Vranceanu (2007)	Ex post	FW (+12)	HICP	IP (HP)	01/99 - 03/06	0.96	4.25	1.28
	Ex post	FW (+12)	HICP	IP [1)]	01/99 - 03/06	0.98	6.80	1.63
Gorter et al. (2007)	Ex post	FW (+12)	HICP	IP (HP)	01/97 - 12/06	0.96	0.04	0.86
	Survey	FW (+12)	CEF [4)]	CEF [4)]	01/97 - 12/06	0.89	1.67	1.65

1) Deviation of IP growth from average growth rate over the sample
2) Average of a linear and quadratic trend measures, the one-sided Christiano-Fitzgerlad filter and the output gaps provided by the OECD and the European Commission.
3) Inflation forecasts based on a poll of a group of forecasters conducted by the Economist every month.
4) Consensus Economics Forecast.

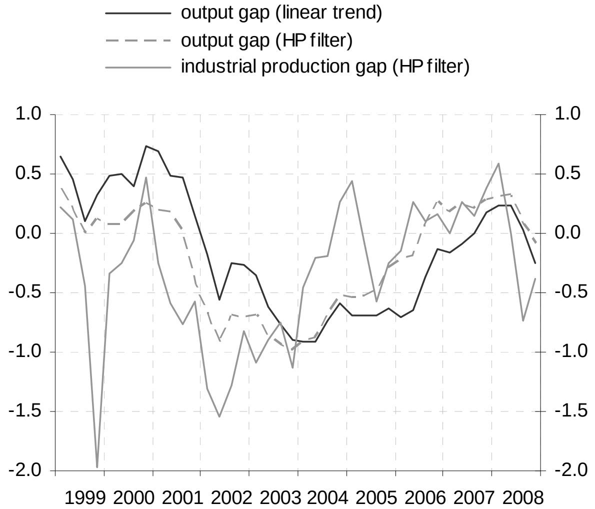
Researchers also face the issue of *model uncertainty*. For instance, the most conventional policy rules are modelled in terms of inflation and the output gap. Policy-makers, however, are unlikely to agree to the hypothesis that all relevant information needed to conduct monetary policy is encapsulated in these two variables. Because central banks face great uncertainty about the state of the economy, they typically monitor a large array of economic and financial indicators to assess the risks to price stability. Simple rules linking changes in the monetary policy instrument to the evolution of a very narrow set of variables ignore the data-rich environment in which policy makers typically form their decisions (see e.g. Bernanke and Boivin 2003). While it is the nature of models to simplify reality, and a policy rule is an admittedly simplistic approach to mimic the behaviour of a central bank, the

[4] Prior to the inception of the ECB and shortly after, some studies examined the Bundesbank's reaction function as a benchmark for the ECB's policy rule (Clarida and Gertler 1996, Faust et al. 2001) or estimated a hypothetical policy rule on the basis of consolidated data for the euro area countries for the late 1980s and 90s (Gerlach and Schnabl 2000, Doménech et al. 2002, Gerlach-Kristen 2003 and Gerdesmeier and Roffia 2004). While of interest itself, papers relying on synthetic euro area data provide little evidence on the ECB's actual interest-rate setting behaviour.

limitation to a confined set of indicators is likely to go hand-in-hand with model misspecification and model uncertainty.

Further, even the most conventional policy rules, specified in terms of inflation and the output gap, are not as straightforward to implement as is sometimes argued. Do policy-makers react to past developments, forecasts or a combination thereof? Which is the measure of economic slack that policy-makers regard as relevant in their decisions? As regards the latter, there are various different concepts, such as potential, trend or flexible-price output, in use by both researchers and econometricians. Figure 1 illustrates that, at times, different measures of the slack in real economic activity are likely to entail a very different policy response depending on both the concept and method used. In some circumstances this is not just a matter of magnitude. While one measure suggests a positive output gap, others might suggest the contrary.[5] As a consequence, the choice of the inflation or output gap indicator is not without impact on the estimated coefficients of monetary policy rules. Table 1 illustrates that estimation results generally vary to a significant extent depending on which indicator for inflation and real economic activity is taken.[6]

Figure 1. Real time measures of real economic activity
(as a percentage of potential activity)



[5] Another prominent example in the literature is the choice for the measure of inflation. Typically, in empirical applications, central banks are assumed to respond to movements in headline inflation. In contrast, structural models usually rely on the use of the GDP deflator to characterise the interest-rate setting behaviour of the monetary authority (see e.g. Smets and Wouters 2003).

[6] Table 1 only shows the forward-looking rules that have been estimated by the various authors. As we will discuss below, forward-looking rules typically outperform backward-looking rules and satisfy a unique equilibrium.

Despite these concerns, standard practice in empirical macroeconomics still requires that a decision is made as to which is the apparently "best" or dominant specification amongst those considered, discarding any information in the alternative specifications. In the current context, this means that researchers examining the ECB's past interest-rate setting behaviour have largely focused on headline inflation and industrial production as a measure of price and economic slack respectively (see Table 1), ignoring any potentially useful information coming from alternative specifications.[7]

There are good reasons to believe that this may not be the best approach. To begin with, reliance on a single specification is clearly at odds with the ECB's two-pillar monetary policy strategy, which emphasises the assessment of a large number of indicators for the conduct of monetary policy (ECB 2004). Moreover, it seems unclear whether a "best" indicator exists at all. Various authors have argued that HICP headline inflation would be the "correct" indicator to be included in any ECB reaction function because of its prominent appearance in the ECB's monetary policy strategy. This assumption is at least doubtful. Would it make sense for the ECB to set policy solely on the grounds of the inflation measure it is held accountable for? In fact, if the ECB were indeed only to react to past inflation developments, it would face difficulties in stabilizing the economy given the significant lags in the transmission of monetary policy. Hence, as a minimum, policy rules should include forecasts of HICP inflation for the relevant horizon. But forecasts, by definition, are surrounded by a large degree of uncertainty. This is why policy-makers consider not only a single "best" forecast, but look at a variety of projections from different institutions, both for inflation and output growth.[8] However, the recommendations borne from these forecasts for setting monetary policy can vary substantially and policy-makers in practice have to pool the information to derive the (weighted) mean forecast that will eventually guide their interest-rate setting behaviour.[9]

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[7] An exception for the euro area is Gerdesmeier and Roffia (2005) who synthesize the information of five different output gap measures and combined them to one that is used in their estimations. For the US Fed Kozicki (1999) is a notable exception. He tested the robustness of his results employing a small range of alternative measures of the output gap.

[8] The non-existence of a single "best" forecast is the most evident in the case of the ECB. Staff projections, which would apply as the most natural candidate for the "best" forecast, are not approved by the ECB's Governing Council, but are only considered as one input among many in the decision-making process.

[9] A widely used reference in this regard is Consensus Economics Forecast who pool every month the forecasts of the largest private and public organisations to form a mean estimate for the main

Taken together, a realistic description of any central bank behaviour requires recognition not only of the fact that policy-makers observe the economy in real time, but also that they form their decision in a "data-rich environment" as stipulated by Bernanke and Boivin (2003). This paper addresses both of these issues for the euro area. In a first step we construct a new comprehensive real-time database for the euro area based only on information available up to one day prior to each interest-rate setting meeting of the ECB's Governing Council since 1999. The database is described in detail in Section II. On the basis of this dataset we examine the ECB's past interest-rate setting behaviour in two complementary ways, each time taking into account the data rich environment in which it operates.

First, we follow the "thick-modelling" approach suggested by Granger and Jeon (2004) who propose to estimate all plausible specifications and to pool the parameter estimates according to some efficiency criteria. We estimate in total a series of 3,330 policy rules for the euro area, exploiting all plausible combinations of the 90 measures of economic activity and the 37 indicators of inflation and inflation expectations. This approach explicitly recognises the large information set at hand to policy makers in practice and does not require taking a stand on the appropriate indicator for inflation and output. Second, we employ a factor-model approach à la Stock and Watson (1999, 2002) and estimate a policy reaction function for the ECB under which the short-term interest rate responds to the state of the economy, as measured by the estimated factors. In so doing, we augment the approach by Bernanke and Boivin (2003) with structurally interpretable factors à la Belviso and Milani (2006) to summarise the information on the basis of which the ECB conducts its monetary policy.

The main findings of the paper can be summarised as follows. First, we show that the prevailing dogma of real-time data, which has mainly been preoccupied with the implications of ignoring data revisions, is not enough to account for the informational rigidities that policy-makers face when forming their decisions. Estimations of policy rules that rely on information that becomes available after the interest-rate setting meeting necessarily overstretch the boundaries of the actual information set available

macroeconomic variables. Traditionally, the combination of forecasts often outperforms the individually best forecast.

to policy-makers in real time and consequently lead to biased estimates due to the endogeneity of the explanatory variables. Second, we show that previous specifications of the ECB's policy rule are likely to be ill-designed in their emphasis on a single or a small set of economic indicators to which the central bank is supposed to react to. In particular, we find that almost 300 estimated rules are able to closely track the ECB's past interest-rate setting behaviour in a meaningful statistical and economic way. This finding highlights that the quest for the "real" or unique policy rule is motivated on false grounds, but that policy-makers receive a large array of signals when deciding on the level of the short-term interest rate. The recommendations borne from this battery of rules is likely to reflect the corridor in which policy makers gear the course of monetary policy. As we will show, ECB policy-makers are neither purely backward nor forward-looking, but react to a synthesis of the available information on the current and future state of the economy.

The remainder of this paper is structured as follows. Section II describes the new real-time database for the euro area. Section III explains the methodology and the results of the thick-modelling exercise. In Section IV we apply the Bernanke-Boivin methodology to conduct a positive analysis of the ECB's past interest-rate setting behaviour. Section V concludes by reviewing the main results from the paper.

II. A new real-time database for the euro area

A striking feature of the past research being done in the area of simple policy rules and the construction of real-time data sets for that purpose has been the preoccupation of economists with the sole role of data revisions.[10] While providing a good overview of the evolution of data over time, such data sets come nowhere close to answering one of the most essential questions that needs to be addressed in any attempt to provide a realistic rendition of the historical pattern of monetary policy: What precisely do policy makers know at each time of decision making?

Traditional real-time data sets are based on standard data frequencies typically used in the economic literature (e.g. monthly or quarterly). Such a procedure necessarily

[10] The "Real-Time Data Set for Macroeconomists" of the Philadelphia Fed as documented by Croushore and Stark (2001) can serve as an example.

forces the economic analysis to link monetary policy decisions to data to which policy-makers may actually have no knowledge at the time of making the decision. To see this, take Orphanides (2001) as an example. Orphanides, like most other contributors in the area of policy rules, estimates the Fed's reaction function at a quarterly frequency.[11] In particular, Orphanides regresses the quarterly average of the federal funds rate on the Greenbook information corresponding to the middle month of each quarter. That is, for the first meeting in each quarter Orphanides implicitly assumes knowledge of the Greenbook in the following month, i.e. data that could not possibly be known to policy-makers at that point in time. At the same time, he does not account for the additional noise in the data resulting from the availability of a new Greenbook prior to each meeting. An obvious implication of this practice is the issue of endogeneity. Given that interest-rate decisions are factually linked to *future* developments in inflation or economic activity, the resulting estimates under least squares are biased.

A step into the direction of realism is to use monthly data instead. Researchers, however, face a non-trivial trade-off when reverting to estimations based on monthly data. Either they accept, as noted on an earlier note, that modelling then requires taking a precise stand on indicators that are in fact available at a monthly frequency, e.g. industrial production or the unemployment rate, or they reduce the frequency of their quarterly dataset to monthly by means of standard interpolation techniques. The latter approach, however, is flawed by introducing artificial dynamics in the resulting dataset that is unlikely to have ever materialized in reality or been observed by policy-makers. Moreover, even if some of the indicators are readily available at a monthly frequency, they need not be available prior to the interest-rate setting meeting.

To avoid these misconceptions that have plagued much of the "real-time" monetary policy literature we construct a new database for the euro area that takes fully into account the true informational limitations faced by the ECB's Governing Council in its decision-making process over the period from 1999 to 2007.

[11] In fact, given the short sample of existence, policy rule estimates for the euro area are generally obtained using monthly data.

Table 2. Releases of euro area real GDP in the first half of 2009

Release	Indicator name	Vintage	available for GovC meeting
8 January 2009	National accounts (GDP)	Q3/2008 - 2nd release	15 January 2009
13 February 2009	Flash Estimate EU and euro area GDP	Q4/2008	5 March 2009
5 March 2009	National accounts (GDP)	Q4/2008 - 1st release	5 March 2009
7 April 2009	National accounts (GDP)	Q4/2008 - 2nd release	7 May 2009
15 May 2009	Flash Estimate EU and euro area GDP	Q1/2009	4 June 2009
3 June 2009	National accounts (GDP)	Q1/2009 - 1st release	4 June 2009
8 July 2009	National accounts (GDP)	Q1/2009 - 2nd release	6 August 2009

In doing so, we construct a database that is meant to describe the past, current and future state of the economy as perceived by policy-makers on the day of the interest-rate setting decision and without the need to assign a particular month or quarter to any of the series. Contrary to other existing studies on policy rules, we do not impose any information on the decision-making body that was not actually at hand at any given point in time. Consider real GDP for the euro area as an example. Though official national accounts data for the euro area are published with a quarterly frequency by Eurostat, policy-makers actually receive new information about the state of the economy every month (see Table 2). By comparing the exact release date with the dates of the Governing Council meetings we are able to compile the information set that was actually available to policy-makers at each meeting. From Table 2 it is easy to see that in some cases a release in one month can only influence the decision in the next month. Other releases may already be outdated at the next meeting. For instance, the flash estimate of 13 February was neither of use for the February meeting that took place on 5 February (too late) nor was it likely to largely influence the March meeting because a more recent release became available to policy-makers on the day of the March decision.[12]

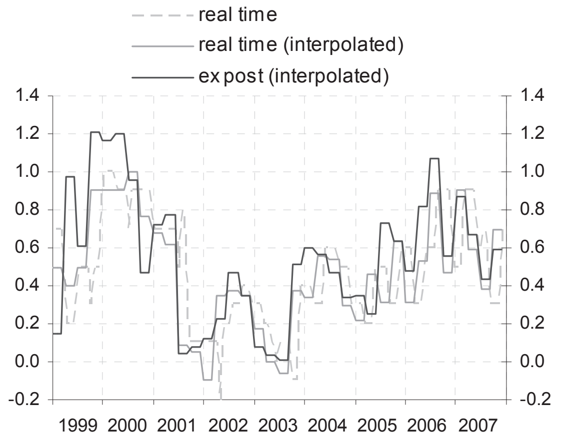
Figure 2 illustrates the differences that emerge when comparing our approach to the current standard practice in the literature. The grey solid line shows the approach chosen by Gerdesmeier and Roffia (2005) who considered a constant interpolation of their real-time quarterly growth rates into monthly data. The black solid line shows a constant interpolation of the first quarter of 2009 vintage of euro area real GDP.[13] As becomes evident, estimations of policy rules that rely on *ex post* revised or real-time

[12] Of course, it could still influence the March decision if the Council responds to the history of events. We take care of this possibility in our estimations.

[13] For a more meaningful and realistic comparison, we already adjusted both interpolated series to reflect the lagged value at each point in time so as to account for the reporting lag of euro area national accounts.

interpolated data necessarily overstretch the boundaries of the actual information set available to policy-makers in real time. Moreover, independent of whether the current or lagged vintage is taken, interpolation of quarterly data does not take into account that policy-makers usually receive signals about different vintages each quarter. For example, in the first quarter of 2009 Eurostat issued information about both the third and the fourth quarter of 2008 (see Table 2). Standard interpolation techniques will always fail to reproduce this crucial observation.

Figure 2. Euro area real GDP
(quarter-on-quarter growth rate, seasonally adjusted)



With two meetings per month until the end of 2001 and one meeting per month thereafter our real-time data set contains a total of 143 data observations for 127 series that are included starting with the information set available to decision-makers on 21 January 1999 and including as a last observation the information available to the Governing Council meeting on 6 December 2007. For the purpose of constructing the real-time data set use was made of various sources, such as the ECB's Monthly Bulletin, Eurostat, Consensus Economics Forecast, IMF, OECD, and others. The choice of our variables was dictated by the ECB's recurrent reference to a particular indicator either in the form of speeches or in official publications.[14] The list of variables can be split into two groups of relevance for the later estimations: a price group and a real economic activity group.[15] The price group contains 37 indicators

[14] In this sense we follow the approach pursued by Gerlach (2007).
[15] The reader is referred to Annex 1 for a complete list of all variables. Our database also includes 30 indicators related to developments in monetary aggregates and financial markets. However, as we are interested in estimating the original Taylor rule that responds to inflation and output only, we did not make use of these indicators. See Gerdesmeier and Roffia (2004) for an exposition of rules with monetary indicators.

and the output group includes 90 variables. Importantly, given the pivotal role played by expectations in the conduct of a stabilizing monetary policy, all groups are composed of a broad range of real-time macroeconomic projections from various institutions for the likely future evolution of key economic indicators, such as real GDP or consumer prices. Furthermore, we collected both soft and hard indicators, which is particularly important in our context given the partially significant lead of soft indicators as compared to hard data.

III. The thick-modelling exercise

We focus our analysis on testing the sensitivity of simple policy rules to changes in the choice of the measures taken for the set of feedback variables that the central bank is assumed to respond to.[16] The resulting range of rule prescriptions may be interpreted as the degree of uncertainty or noise stemming from the different signals policy-makers receive from the broad range of indicators available before each interest-rate setting meeting. In doing so, we need to make prior assumptions regarding the general policy framework underlying our sensitivity analysis. Parallel changes to the specification of the rule would not allow for disentangling the differences resulting from the choice of the measure or the design of the policy rule. Various different specifications have been proposed in the literature so far. Consider first the very general family of monetary policy rules that nests a variety of the proposed specifications (see e.g. Clarida et al. 2000): [17]

$$(1) \qquad i_t = \rho i_{t-1} + (1-\rho)(r^* + \pi^* + \beta_\pi(\mathbb{E}_t[\pi_{t+h}] - \pi^*) + \beta_y \mathbb{E}_t[y_{t+k} - y^*])$$

where i_t is the recommended level for the policy rate, r^* the real equilibrium interest rate, π^* the inflation target of the monetary authority, π_t a measure of price developments and $(y_t - y^*)$ a measure of economic slack. The integer parameters h and k refer to the forecast horizon for inflation and output respectively. This specification collapses to Taylor's original rule when $r^* = 2$, $h = k = \rho = 0$ and $\beta_\pi = \beta_y = 0.5$.

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[16] Our analysis is therefore in the spirit of Granger and Jeon (2004).
[17] We follow Clarida, Galí and Gertler (1999,2000) in that we consider the nominal equilibrium interest rate to consist of the real equilibrium rate r^* and the inflation objective of the central bank rather than last period's inflation rate as is often used.

Allowing $\rho \neq 0$ embeds a gradual, partial adjustment of the policy rate to the original Taylor rate, reflecting the possibility of interest rate smoothing.[18]

Estimation of policy rules in the form of equation (1) is common in the literature. However, estimation of these rules is not without problems. As pointed out by Orphanides (2003) a critical aspect of policy rules in the form of equation (1) is the emphasis they place on a concept of the economy's potential level of economic activity, y^*, for calculating the output gap. In theory, as noted above, various different notions of potential output exist (e.g. flexible-price-output, the steady-state-output, the NAIRU, the linear and HP-filtered-trend) and it is unclear which of the concepts is the most appropriate for estimating the cyclical position of the economy. The choice is not without consequences as demonstrated by McCallum and Nelson (2004). They show that the use of a mistaken concept of the output gap can imply major welfare losses within a class of policy rules that rely upon measures of the output gap.[19] Similarly, Orphanides (2003) shows that the key source of the policy failure associated with the Great Inflation in the United States was the pursuit of activist policies based on real-time estimates of potential output that were severely overstating the economy's capacity at that time.

Assuming that policy-makers have perfect knowledge in real-time over such latent variables is therefore highly unrealistic, if not problematic. As a consequence, a number of authors (McCallum 2001, Orphanides et al. 2000, Orphanides 2003, Orphanides and Williams 2002, Leitemo and Lønning 2006, Williams 2006) advocate the use of rules that are based on growth rates as they suffer from fewer measurement problems.[20] Consider the generalised family of "growth" rules:

$$(2) \qquad i_t = \rho i_{t-1} + (1-\rho)(r^* + \pi^* + \beta_\pi(\mathbb{E}_t[\pi_{t+h}] - \pi^*) + \beta_{\Delta y}\mathbb{E}_t[y_{t+k} - y_{t+k-1}])$$

---

[18] The inclusion of policy gradualism can be theoretically justified on several grounds, see e.g. Woodford (1999) and Sack and Wieland (2000).

[19] They compare welfare losses with a rule using the McCallum and Nelson (1999) measure of the output gap, which resembles the flexible-price-output, and a rule employing a simple linear trend as a measure of potential output.

[20] As Orphanides (2003) points out errors in the measurement of the output gap are highly serially correlated. As a result, mismeasurements in the *level* of the output gap are more pronounced than in the first difference of the output gap.

where, contrary to the Taylor-type rules in equation (1), these rules do not any longer require knowledge of the potential level of output or the natural rates of unemployment for setting policy. Such "growth" rules are hence a simple and effective approach for dealing with the ignorance about the degree of uncertainty surrounding the estimates of potential output in real time. Avoiding the level of the output gap in the estimation of policy rules is a robust approach for hedging against non-trivial measurement problem.

Besides their usefulness in this respect, there are two other paramount factors that speak in favour of using "growth" rules over other Taylor-type rules. The first factor relates to the optimality of "growth" rules. There is now plenty of evidence that "growth" or "difference" rules may outperform standard Taylor rules in their capacity to stabilise inflation and output volatility (Orphanides and Williams (2002), Walsh (2003), Stracca (2006)).[21] Another criterion in favour of "growth" rules is rather pragmatic albeit no less important. It is the ECB's notorious dismissal of the output gap as a reliable indicator for the conduct of monetary policy. This can be seen on various occasions. For instance, as noted already by Gerlach (2007), the ECB never refers to output gaps in its official communications or publications, such as its Monthly Bulletin. The ECB itself is also not secretive about its thoughts on the usefulness of the output gap. For example, Papademos (2005) said that natural rates or the output gap "do not play a prominent role in the ECB's strategy for determining the monetary policy stance". President Trichet in November 2004 was even clearer in stating that it would even "be dangerous to derive monetary policy decisions from such an indicator. In my view, the example of the "output gap" demonstrates that theoretical economic models and monetary policy practice are, at times, quite far apart." Hence, if the objective of the paper lies in identifying a robust policy rule for the euro area, it would seem cynical to impose a reaction of the ECB to a variable that we know *ex ante* it deliberately discards as an input to its decision-making process.

Taken together, there is strong theoretical and empirical support for the use of "growth" rules when it comes to examining the ECB's past interest rate setting. We therefore proceed in estimating policy rules in the form of equation (2) for the ECB

[21] "Difference" rules are usually referred to as rules with a smoothing coefficient of one.

over the period from 1999 to 2007. The analysis is carried out using our real-time database described in Section II. As the database consists of both past and contemporaneous data as well as of projections for inflation and real economic activity, we can estimate both backward and forward-looking policy rules. For the most part, estimation of forward-looking rules relying on *ex post* revised data has called for the use of instrumental variable (IV) techniques to counter the problem of endogeneity (e.g. Clarida, Galí and Gertler 2000). Although in theory GMM estimation has been shown to produce consistent estimates under some assumptions, the choice of the instruments is critical for determining the finite sample properties, in particular the bias, of the IV estimator. One thing to remember is that unlike ordinary least squares (OLS) estimation under a zero conditional mean assumption, IV methods are never unbiased when at least one explanatory variable is endogenous (Wooldridge 2001). Even in large samples IV methods can be ill-behaved if the instruments are weak.[22] For our analysis, and similar to Orphanides (2001), it is not necessary to instrument for the various measures of inflation and real economic activity. The reason is that our real-time database is constructed to reflect only information actually available to policy-makers at any given point in time, avoiding the issue of endogeneity plaguing estimations employing *ex post* revised data. Least squares estimates will therefore provide consistent and unbiased estimates of the parameter space under standard assumptions.

III.1 Selection of rules

We begin by estimating a total of 3,330 policy rules for the euro area, combining 37 inflation measures and 90 indicators of real economic activity. Naturally, not all estimated rules are likely to be meaningful from either a statistical or economic point of view or both. As mentioned above, we are not claiming that any of these rules mirrors the "real" reaction function of the ECB, but that the bulk of rules reflects the degree of uncertainty and the range of signals policy-makers face when combining all available indicators. We apply four filters that reduce the number of specifications to a set of rules that delivers a meaningful approximation of the ECB's past interest-rate setting behaviour. The first filter is of a purely statistical nature. We require the

[22] Another potential problem with applying IV methods is that the standard errors have a tendency to be large. The magnitude of the errors depends, among others, on the quality of the instruments.

estimates of β_π and β_y to be statistically significant at least at the 10% confidence level. This first selection reduces the number of rules to 617, i.e. slightly more than 2,700 specifications are rejected by the data solely on the grounds of a poor statistical description of the underlying data generating process.

In a second step we restrict the estimates of β_π and β_y to be strictly positive.[23] That is, we only consider rules that have a minimum of stabilising properties and are in line with the ECB's primary objective of maintaining price stability. Only if monetary policy responds to an increase in both inflation and output growth by systematically raising the policy rate, the central bank will be able to stabilise the economy and deliver price stability. Note that, at this stage, we do not require single rules to fulfil the Taylor principle, i.e. the requirement of a more than proportional response of the nominal interest rate to movements in the inflation rate. While the Taylor principle does not necessarily have to hold for each and every specification, we would expect it to hold on average (see Section III.2). The second selection criterion further reduces the number of considered rules to 591.

The third filter applied to the reduced set of rules relates to some identification issues in estimating equation (2). In the absence of further assumptions estimation of equation (2) will only allow identifying the term $r^* + (1- \beta_\pi)\ \pi^*$, but not r^* or π^* separately. While exact identification of these equilibrium measures is not the focus of our analysis, and indeed all previous studies on the euro area policy rule literally neglect this issue, we still require our rules to produce reasonable estimates for both concepts.[24] We pursue the reverse of the approach proposed by Clarida, Galí and Gertler (2000) and take the sample average of each inflation indicator as a measure of the implicit inflation objective to recover an estimate of the real equilibrium interest rate.[25] For the rule to be accepted, we require the resulting equilibrium interest rate to

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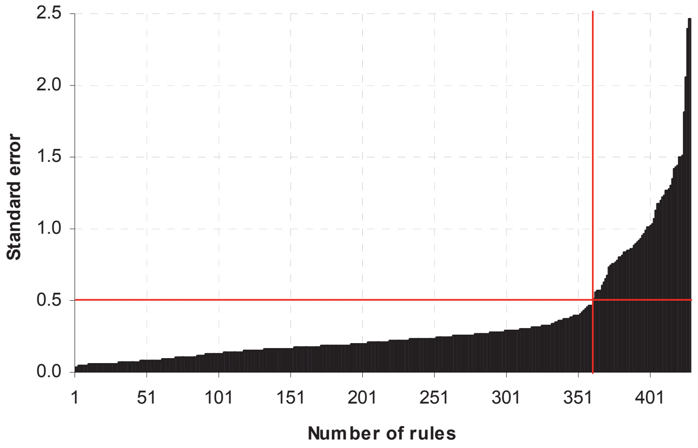
[23] The only exception is the reaction to the unemployment rate or the forecast thereof. An increase in the unemployment rate should, on average, trigger a monetary policy easing. We therefore multiplied all series related to the unemployment rate with minus one to allow interpreting the output coefficient in a similar manner to the other measures of economic activity.

[24] Several avenues have been proposed in the literature to identify either the natural rate of interest or the inflation objective. For instance, given that the US Fed has not announced an explicit inflation target, Clarida, Galí and Gertler (2000) took the sample average of the real interest rate as a measure of the equilibrium real rate, allowing them to recover an estimate of the implicit inflation target π^*.

[25] One way that would permit identifying the natural rate of interest r^* in studies for the euro area would be to assume target inflation π^* to take a value close to the ECB's definition of price stability of

lie within the confidence interval suggested by Benati and Vitale (2007). They show that natural rate estimates in the euro area have historically been characterised by a significant extent of uncertainty, to the point that the confidence interval corresponding to one standard deviation, i.e. the 16th and 84th percentiles of the simulated distributions, stretches from about -2 to 6 per cent in the period from 1999 to 2006 in the euro area.[26] Applying this range to our estimated rules further reduces the number of considered specifications to 428 rules.

Figure 3. Standard errors of the economic growth variable



Finally, from the remaining rules we discard those specifications that have standard errors of the estimated coefficients significantly different from the general distribution. Figure 3 illustrates this trimming procedure based on the distribution of the standard errors of the economic growth variable. As can be seen from Figure 3 the standard errors of around 85% of rules ranges between 0 and 0.5. Thereafter, the standard errors start to grow exponentially and become significantly different from the general distribution of errors of the entire range of estimated rules. We therefore discard all specifications with a standard error of the economic growth variable larger than the threshold value of 0.5. In a similar vein, we ignore rules with a standard error of the smoothing coefficient larger than 0.04, a standard error of the constant larger than 0.7 and a standard error of the coefficient of the inflation weight larger than 1.5

"close, but below 2%". However, while this approach appears as a reasonable approximation in specifications featuring HICP headline inflation (the index for which the ECB defined its price stability objective) or the forecasts thereof, it is of no avail in rules that consider alternative inflation measures, such as wage growth projections, unit labour costs or any sub-index of the HICP.

[26] The sample average of the *ex post* real interest rate in the euro area, calculated as the difference between the EONIA and annual HICP inflation, is 1.18.

(see Annex 2 for the corresponding charts). This final selection reduces the number of considered rules to 291. That is, around 9 per cent of the original 3,330 rules deliver a meaningful statistical and economic description of the ECB's past interest-rate setting behaviour. In the next section we discuss the estimated properties of these rules.

III.2 Estimation results

Table 3 presents an overview of the least squares estimates based on real-time data. We report simple averages of the estimated coefficients, standard errors and the R^2. That is, we assume that policy-makers assign equal weight to each of the relevant combinations of inflation and output indicators when forming their policy decision.[27] Given that the whole idea behind thick modelling is to hedge against possible misspecifications, assigning equal weight to each indicator minimises the risks associated with model uncertainty.

Table 3. Mean estimates of policy rules for the euro area (1999 to 2007)
(stand. errors in brackets; all coefficients statistically significant at least at the 10% confidence level)

	No of rules	Share of total	ρ	r*	β_π	β_y	SEE	R^2
All rules	291		0.92 (0.03)	-0.53 (0.37)	1.25 (0.46)	0.94 (0.19)	0.2007	0.9562
Forward-looking in inflation and output	48	16.5%	0.91 (0.03)	-1.06 (0.39)	2.22 (0.81)	1.05 (0.15)	0.2002	0.9564
Backward-looking in inflation and output	117	40.2%	0.92 (0.03)	-0.20 (0.36)	0.55 (0.18)	0.82 (0.2)	0.2006	0.9562
Mixed rules	126	43.3%	0.91 (0.03)	-0.64 (0.39)	1.52 (0.58)	1.00 (0.18)	0.2010	0.9560

A number of interesting results stand out from the estimation. First, considering all 291 rules, which include both backward and forward-looking specifications, the mean estimate of β_π equals 1.25, which is noticeably above unity and is indicative for the fact that real interest rates in the euro area are likely to have risen in response to an increase in inflation over the estimation sample. However, Table 3 clearly shows that the strength of the ECB's response to movements in inflation critically depends on whether the rule is backward or forward-looking. Policy rules that are specified only in terms of expectations for both inflation and output bear a much larger response (β_π = 2.22) to inflation as other rules would predict. Purely backward-looking rules, which respond to lagged or contemporaneous variables, have, on average, an inflation

[27] We experimented with various weighting schemes, such as with the standard errors or the R^2, to compute the average, but the general results remain virtually identical.

coefficient nowhere near one (β_π = 0.55). Four reasons are likely to drive the difference in the response. First, a more activist behaviour by policy-makers in rules based on projections can be partly explained by the larger degree of inertia present in most forecasts. For instance, the average standard deviation of the 13 HICP headline projections considered in our estimations amounts to 0.27, which is less than half the standard deviation of realised past HICP headline inflation (0.59).[28] Second, a stronger response to projected inflation underlines the ECB's strong commitment to anchor medium to longer term inflation expectations. Any deviation of these indicators from their long-run average is strongly accommodated by the ECB.[29] Third, a coefficient on the inflation variable larger than one in forward-looking rules is indicative for the fact that successful stabilisation policy requires a more forward-looking approach. Because monetary policy operates with a lag, real interest rates need to rise in response to an increase in *projected* inflation, not past inflation. Finally, by its nature, a monetary policy aiming at delivering price stability over the medium term, which is the ECB's defined objective, should not respond too strongly to short-term movements in past inflation, especially after the economy is hit by a large shock. This seems all the more warranted at the current juncture where short-term inflation developments are characterised by a high degree of volatility and a medium-term orientated view is indispensable in formulating the response of monetary policy.[30]

The extent of variation in the output coefficient β_y is much less substantial. It ranges, on average, from 0.82 in the fully backward-looking rules to 1.05 in the purely forward-looking models, with the mean over all rules being estimated at 0.94. The policy smoothing coefficient on the lagged interest-rate is even less dependent on the measure of inflation and economic activity and indicates a generally high degree of inertia, around 0.9, in the ECB's policy response. An interesting result is the fact that the equilibrium real interest rate is found to be slightly negative on average over the estimation sample. Only around 25% of all final rules have a positive rate. Naturally, the identification of the equilibrium real rate depends, as discussed before, on the

[28] The same holds true for real annual GDP growth, for which the average standard deviation of its forecasts accounts for 0.56, which compares to 0.95 for the latest available release.
[29] The rate hike of July 2008 is a forceful demonstration of the ECB's commitment in this respect.
[30] In this sense, even a two-year horizon, which is the widest horizon of inflation expectations used in this study, may be too short at present.

assumption of the inflation target in each specification. The results should therefore be interpreted with caution. Nevertheless, the low or even negative level of the average real rate confirms, on the one hand, the results by Benati and Vitale (2007), who find a non-trivial probability for the equilibrium rate to be negative in the euro area over a similar sample, and, on the other hand, the low interest-rate environment prevailing in the euro area since the advent of the single monetary policy.

Figure 4. The inflation and output coefficient: minimum, mean and maximum

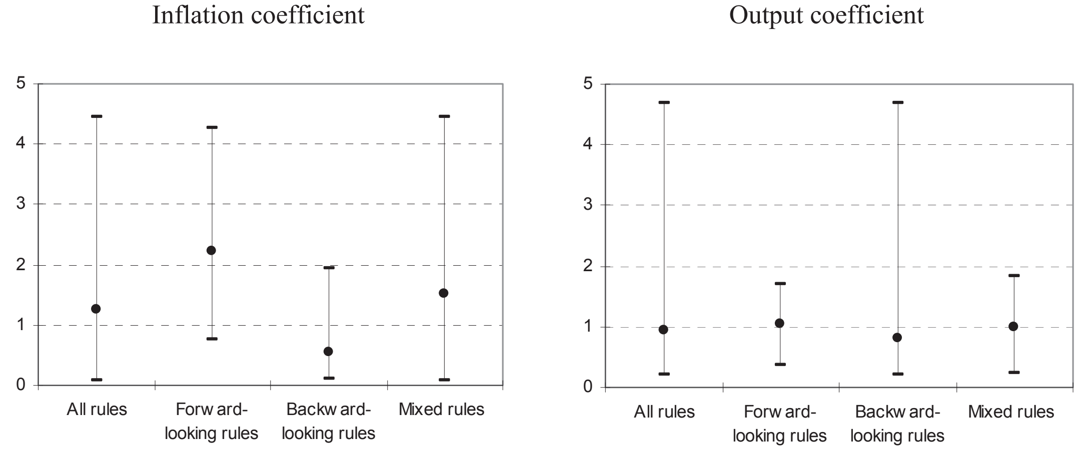


Figure 4 shows the distribution of the coefficients across different rules. As becomes apparent from Figure 4 the range of coefficients can, at times, be relatively large, underlining the plurality of signals that policy-makers receive from the different indicators and combinations thereof. In other words, rules that share similar statistical properties, given the homogeneous selection criterions applied to all rules in terms of goodness of fit, statistical significance or the size of the standard errors, can result in very different descriptions of the ECB's past interest rate setting. The large differences highlight the potentially misleading recommendations that can emerge from the estimation of policy rules based on a single or a small set of indicators.

At the same time, large ranges are not necessarily the result of a thick-modelling exercise. For example, the inflation coefficients in backward-looking rules or the output coefficients in forward-looking rules are clustered along a relatively small range of values (see Figure 4), suggesting that the choice of the indicators plays a less dominant role in these rules as compared to others. In a similar vein, the distributions of the coefficients are in most cases not normal, but skewed towards the lower tail, implying that the broad mass of coefficients is centered around a smaller range.

Figure 5. The inflation and output coefficients: distribution over all 291 rules

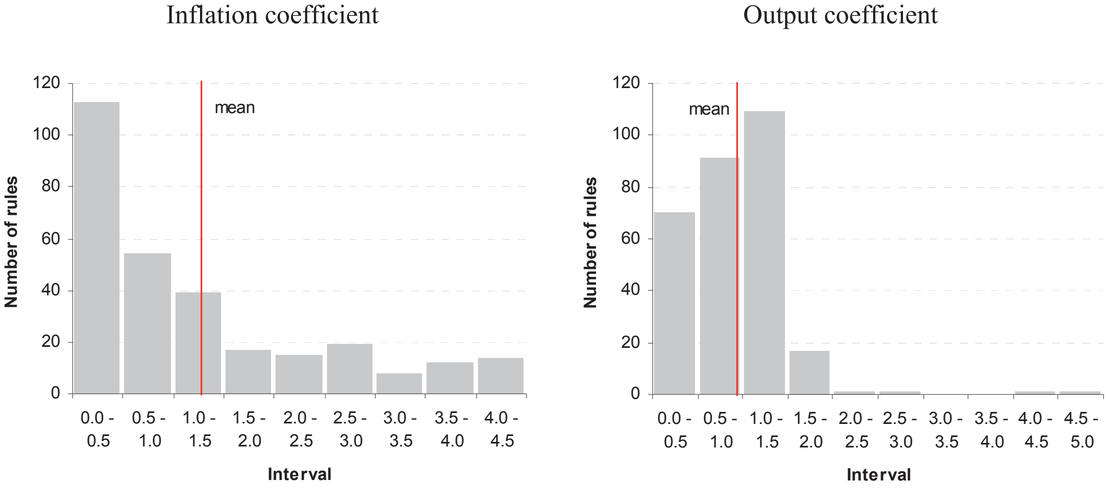
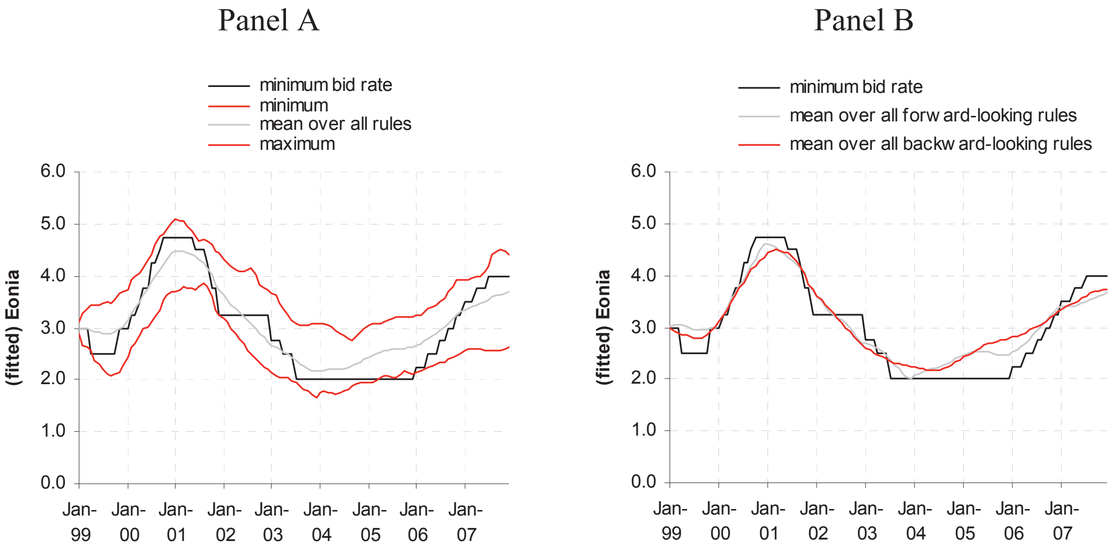


Figure 5 illustrates this on the basis of a histogram of the inflation and output coefficients over all 291 rules. As regards the inflation coefficient, 206 specifications, or around 71% of all final rules, are estimated with a coefficient between 0 and 1.5, while less than a third of all rules share the much larger interval between 1.5 and 4.5. The distribution is even more highly skewed for the estimated output coefficients. In this case, 93% of all rules have a coefficient of below 1.5. Put another way, although non-trivial differences exist in the estimated coefficients of both output and inflation across the entire battery of rules, the estimates are largely confined to a relatively narrow and homogeneous range.

Figure 6. Fitted values of the estimated policy rules



This can also be seen by plotting the corridor of recommendations borne from these rules. Figure 6 (Panel A) shows the very close adherence of the mean fitted values to the ECB's actual policy-making. The close fit does not originate from any particular type of policy rule. Panel B of Figure 6 illustrates that, on average, both backward- and forward-looking rules provide a similar depiction of the recommended path of policy rates. More strikingly, the actual policy rate virtually lies at any point in time within the corridor prescribed by the range of policy rules, the only exception being the extended period of low interest rates in late 2005.[31] In a way, the close fit is a validation of the fact that the ECB's policy-makers indeed consider a broad range of indicators, while their decisions seem to converge to the average of the policy path prescriptions. That does not mean that the rules recommending very large or very low interest rates are less suited to describe ECB policy-making. Note that these rules passed the strict selection criteria presented in Section III.1. These rules merely highlight the fact that, according to the development of some inflation and output growth indicators, interest rates should on average be higher or lower than what the majority of rules would predict. Policy-makers should not ignore these signals, but consider them as one input among many.

Table 4. Mean estimates of policy rules for the euro area: inflation measures
(stand. errors in brackets; all coefficients statistically significant at least at the 10% confidence level)

	No of rules	Share of total	ρ	r*	β_π	β_y	SEE	R^2
Forward-looking in inflation [1)]	108	37.1%	0.92	-0.67	2.48	1.02	0.2016	0.9558
			(0.03)	(0.35)	(0.94)	(0.17)		
Projections for the current year	26	8.9%	0.92	-0.59	1.23	0.98	0.2025	0.9555
			(0.03)	(0.34)	(0.58)	(0.17)		
Projections for the next year	82	28.2%	0.92	-0.69	2.88	1.03	0.2013	0.9559
			(0.02)	(0.35)	(1.05)	(0.17)		
Backward-looking in inflation [1)]	183	62.9%	0.91	-0.45	0.51	0.89	0.2002	0.9564
			(0.03)	(0.39)	(0.17)	(0.19)		
HICP rules	43	14.8%	0.91	-0.27	0.64	0.98	0.2016	0.9558
			(0.03)	(0.38)	(0.27)	(0.18)		
IPP rules	105	36.1%	0.92	-0.48	0.31	0.71	0.1998	0.9565
			(0.02)	(0.41)	(0.1)	(0.2)		
Wage growth rules	35	12.0%	0.90	-0.57	0.98	1.30	0.1994	0.9567
			(0.03)	(0.34)	(0.28)	(0.18)		

1) Output growth measures can be past, contemporaneous or projections.

Table 4 shows in more detail the properties of the estimated coefficients depending on the measure of inflation that is taken. An interesting result is the stark difference in

[31] With the benefit of hindsight an earlier removal of the policy accommodation in line with the recommendations of the estimated policy rules might have been warranted.

the inflation coefficient in rules with inflation projections for the current and next year. The ECB seems to react almost twice as strongly to movements in inflation expectations for the next year as compared to the current year. Two other noteworthy results stand out. First, rules that include industrial producer prices as a measure of inflation make up a large part of the finally selected specifications (36.1%).[32] This measure hardly appears in other studies examining the ECB's interest-rate setting behaviour, emphasising the importance of the thick-modelling exercise. Second, rules that are specified in terms of wage growth indicators result in a relatively large inflation coefficient, in particular when compared to other backward-looking rules.[33] Such behaviour on part of policy-makers can partly be explained by the lagged effects of price developments in labour markets on headline inflation. Past increases in labour costs may still exert upward pressure on consumer prices in the future, therefore requiring a stronger response to these indicators as compared to other inflation measures.

Table 5. Mean estimates of policy rules for the euro area: output measures
(stand. errors in brackets; all coefficients statistically significant at least at the 10% confidence level)

	No of rules	Share of total	ρ	r*	β_π	β_y	SEE	R^2
Forward-looking in output 1)	114	39.2%	0.91	-0.96	1.20	1.03	0.1998	0.9566
			(0.03)	(0.43)	(0.44)	(0.17)		
Real GDP growth	63	21.6%	0.90	-1.15	0.87	1.23	0.1992	0.9569
			(0.03)	(0.43)	(0.38)	(0.18)		
Private consumption growth	14	4.8%	0.92	-1.30	1.89	1.41	0.2028	0.9553
			(0.02)	(0.55)	(0.63)	(0.28)		
Investment growth	30	10.3%	0.91	-0.54	1.70	0.49	0.1995	0.9567
			(0.02)	(0.35)	(0.51)	(0.08)		
Industrial production growth	7	2.4%	0.93	-0.42	0.64	0.74	0.2005	0.9563
			(0.02)	(0.5)	(0.29)	(0.2)		
Backward-looking in output 1)	177	60.8%	0.92	-0.25	1.28	0.88	0.2013	0.9559
			(0.03)	(0.34)	(0.47)	(0.2)		
Real GDP growth	20	6.9%	0.90	-0.42	0.82	1.17	0.2008	0.9561
			(0.03)	(0.35)	(0.36)	(0.21)		
Private consumption growth	59	20.3%	0.92	-0.65	1.79	1.08	0.2030	0.9551
			(0.03)	(0.39)	(0.64)	(0.22)		
Investment growth	65	22.3%	0.92	0.27	0.99	0.66	0.1990	0.9569
			(0.02)	(0.23)	(0.37)	(0.16)		
Domestic demand growth	33	11.3%	0.93	-0.48	1.24	0.79	0.2030	0.9551
			(0.02)	(0.48)	(0.46)	(0.22)		

1) Inflation measures can be past, contemporaneous or projections.

[32] We consider four measures of industrial producer prices: headline, capital goods, manufacturing goods and intermediate goods.
[33] The two measures capturing price developments in labour markets are unit labour costs and compensation per employee.

Finally, Table 5 highlights the differences in the estimated coefficients that emerge with the use of different choices for the output growth measure. ECB policy-makers seem to react very differently to the type of projected variable. They appear to respond most actively to the annual growth rate of real GDP and private consumption. Interestingly, this is true for both backward- and forward-looking rules. In particular, there is hardly any difference in the ECB's estimated response to forecasts (β_y = 1.23) or past figures (β_y = 1.17) on real GDP growth. Another finding is of importance as regards a comparison of the results with previous attempts to describe the ECB's past interest-rate setting behaviour. While the vast majority of these studies had employed industrial production as a measure of economic activity, this indicator seems to play a minor, if not subtle role in growth rules and after applying the selection criterions outlined in Section III.1. Out of 148 rules that could possibly nest industrial production as a measure of economic activity, only seven rules were finally selected as providing an economically and statistically meaningful description of the ECB's conduct of monetary policy over the estimation sample. None of these rules are backward-looking in industrial production, which is the dominant assumption in most previous examinations of the ECB's policy setting.

III.3 Confidence intervals for thick modelling

In his seminal paper Taylor (1993) proposes a monetary policy reaction function that features no distinct central bank preference over the two objectives of stabilising inflation and output around target. This can be seen by the equal weights of 0.5 that Taylor assigns on the monetary authority's reaction to inflation and output. The rich spectrum of policy rules that we consider in this paper can be used as a laboratory to investigate the relevance of the originally specified Taylor rule in the historical conduct of monetary policy in the euro area.

In doing so, we test whether the confidence intervals from thick modelling include the weights of 0.5 suggested in the Taylor rule. We follow Granger and Jeon (2004) and construct the confidence intervals by "bagging" (bootstrap aggregation). For each of the 291 estimated rules we stationary bootstrap the residuals over 10000 iterations and re-estimate the rule to reproduce the main properties of the data. The original rule is then estimated using the bootstrapped data. For each iteration, 291 different sets of the estimated coefficients are pooled to make the thick model estimates. Table 6 summarises the mean estimates over all previously estimated 291 policy rules as well as the average estimates over all 10000 bootstrap regressions for all 291 rules together with the corresponding standard deviations.

Table 6. Taylor rule bootstrapping results

	Thick modelling				Bootstrap aggregation			
	ρ	r^*	β_π	β_y	ρ	r^*	β_π	β_y
All rules	0.92	-0.53	1.25	0.94	0.92	-0.53	1.25	0.94
	(0.03)	(0.37)	(0.46)	(0.19)	(0.00)	(0.19)	(0.44)	(0.12)

In line with the results reported in Granger and Jeon (2004) our bootstrap procedure produces smaller bagging-implied standard errors compared to those obtained by simple averaging over the thin specifications. This is particularly true for the S.D.s of the smoothing, the real interest rate and the output weight coefficients. The 95% confidence intervals for the inflation and output coefficients implied by the bootstrap procedure amount to (0.377, 2.122) and (0.696, 1.180) respectively. In contrast to Granger and Jeon (2004) who document a non-compliance of the magnitude of the US monetary policy reaction to inflation with the original Taylor (2003) value we find no evidence to reject the hypothesis that the ECB has been responding to inflationary pressures in line with the Taylor's original specification. In contract, there is empirical evidence to suggest that the ECB has been more aggressive in its reaction to real activity developments than proposed by Taylor (2003).

IV. Principal component analysis

Thick-modelling deals with the "data-rich" environment in which policy-makers operate by synthesising the estimation results of many alternative specifications. An alternative to this approach is to condense the information of large datasets *prior* to the estimation by extracting common factors that can explain some of the co-movement in the data and to use these factors in macroeconomic modelling. Amongst the earliest research in this field have been the seminal papers by Stock and Watson (1999) and Forni et al. (2000).

In what follows we adopt a Principal Component factor-extracting approach that is designed to summarize the essential dynamics contained in our real-time data set in a narrower set of factors. While a fundamental feature of most existing research in this field has been the practice of extracting factors from the whole set of macroeconomic series available (e.g. Bernanke and Boivin 2003, Bernanke, Boivin and Eliasz 2005), the factors extracted in this way do not carry a meaningful structural interpretation. To avoid this limitation we follow the approach suggested by Belviso and Milani (2006) who suggest the use of structurally interpretable factors in the econometric analysis.

We assume that the variables in our real-time data set are contained in the $M \times 1$ vector X_t (*M* stands for the number of all variables present in the data set) while Y_t contains the ECB policy instrument with $t = 1, 2, ..., T$. We assume further that the dynamics of the variables in X_t is governed by:

(3) $$X_t = \Lambda F_t + \varepsilon_t$$

where F_t is a $K \times 1$ vector of unobservable fundamental factors, ε_t is a vector of errors that satisfy $E(\varepsilon_t \mid F_t) = 0$ and $E(\varepsilon_{m,t} \mid \varepsilon_{n,t}) = 0$ for all $m, n = 1, ..., N$ and $m \neq n$ and Λ is a conformable matrix of factor loadings. We split our real-time data set X_t into subvectors X_t^1, X_t^2,…., X_t^I each containing series relating to the same macroeconomic concept and such that X_t^i represents an $N_i \times 1$ vector satisfying $\sum_i N_i = N$. The fundamental feature allowing us to obtain factors that have a clearly distinct structural interpretation is our assumption that each subvector X_t^i is related to only a particular subset of the fundamental factors vector F_t. In particular, we propose a division of F_t into F_t^1, F_t^2,…., F_t^I with F_t^i being a $K_i \times 1$ vector such that $\sum_i K_i = K$ and $K_i < N_i$ for all *i*. Then the dynamics of X_t^i is assumed to be captured by exactly one subfactor F_t^i as given by:

(4) $$\begin{bmatrix} X_t^1 \\ X_t^2 \\ ..... \\ X_t^I \end{bmatrix} = \begin{bmatrix} \Lambda_1^f \; 0 \ldots 0 \\ 0 \;\; \Lambda_2^f \ldots 0 \\ \ldots\ldots\ldots\ldots \\ 0 \;\; 0 \;\; \ldots \Lambda_I^f \end{bmatrix} \times \begin{bmatrix} F_t^1 \\ F_t^2 \\ .... \\ F_t^I \end{bmatrix} + \varepsilon_t$$

with $E(\varepsilon_t \mid F_t^1, ..., F_t^I) = 0$ and $E(\varepsilon_{m,t} \mid \varepsilon_{n,t}) = 0$ for all $m, n = 1, ..., N$ and $m \neq n$. Each subfactor F_t^i is assumed to be the first principal component of the respective variable subgroup X_t^i; that is, the principal component that captures the greatest fraction of the total variability of the subgroup X_t^i.

We partition our entire real-time data set into three inflation and three output growth groups that give rise to six distinct factors used in the subsequent econometric analysis:[34]

- Past inflation
- "Current year" inflation projections
- "Next year" inflation projections
- Past output growth
- "Current year" output growth projections
- "Next year" output growth projections

Prior to the extraction of the factors, each time-series is demeaned and standardized to have a unit variance. This initial standardization is performed in order to prevent more volatile series from overly influencing the obtained factors. However, to obtain a meaningful interpretation of the estimated coefficients, there is a need to restandardise each principal component before the estimation. Normally, the component series with the highest correlation with the principal component is taken for the restandardisation (see e.g. Kapetanios 2004). However, given that this procedure is to a large extent arbitrary but, at the same time, linked with non-negligible repercussions on the estimated coefficients in a policy rule context, we choose to normalise each extracted factor by the means and standard deviations of all component series that have a correlation with the respective first principal component of more than 80 per cent. Given that no logical preference can be made for any of the resulting series, we proceed in estimating the policy rules with all restandardised factors and average the estimation results over all series that belong to the same group. In so doing, we hedge against the arbitrariness in basing the first and second moments of the principal component on just a single component series.

[34] The reader is referred to Annex 1 for a description of the composition of each of the groups.

IV.1 Estimation results

This procedure results in multiple estimation combinations similar to the thick-modelling approach. In total, we estimate 2,088 policy rules on the basis of the restandardised principal components. We apply the same statistical and economic filters as outlined in Section III.1, the only exception being the trimming by standard errors since the dispersion of the latter was very limited. The filtering reduces the number of meaningful rules to 390. Table 7 presents the mean estimates of the selected factor-based rules.

Table 7. Mean estimates of factor-based rules for the euro area (1999 to 2007)
(stand. errors in brackets; all coefficients statistically significant at least at the 10% confidence level)

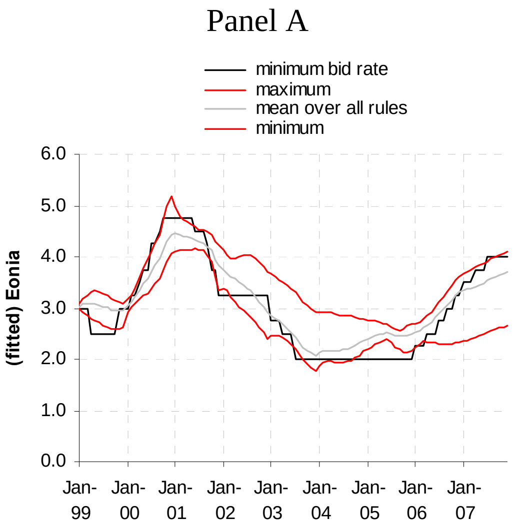
	ρ	r^*	β_π	β_y	SEE	R^2
All rules	**0.89**	**3.13**	**0.72**	**0.38**	**0.2004**	**0.9563**
	(0.03)	(0.17)	(0.23)	(0.05)		
Purely forward-looking rules	**0.88**	**3.73**	**1.31**	**0.52**	**0.1960**	**0.9582**
	(0.03)	(0.14)	(0.31)	(0.06)		
Inflation (next year) and output growth (current year)	0.90	3.69	0.88	0.40	0.1983	0.9572
	(0.02)	(0.15)	(0.36)	(0.05)		
Inflation (next year) and output growth (next year)	0.86	3.77	1.74	0.64	0.1937	0.9592
	(0.03)	(0.13)	(0.27)	(0.06)		
Purely backward-looking rules	**0.90**	**2.42**	**0.20**	**0.14**	**0.2042**	**0.9546**
	(0.04)	(0.2)	(0.1)	(0.02)		
Mixed rules	**0.90**	**2.97**	**0.50**	**0.36**	**0.2021**	**0.9555**
	(0.04)	(0.18)	(0.23)	(0.06)		
Inflation (past) and output growth (current year forecast)	0.86	2.81	0.20	0.39	0.1975	0.9575
	(0.04)	(0.1)	(0.05)	(0.04)		
Inflation (past) and output growth (next year forecast)	0.91	2.82	0.20	0.54	0.2060	0.9538
	(0.04)	(0.2)	(0.09)	(0.11)		
Inflation (next year forecast) and output growth (past)	0.92	3.27	1.11	0.14	0.2029	0.9552
	(0.02)	(0.24)	(0.54)	(0.03)		

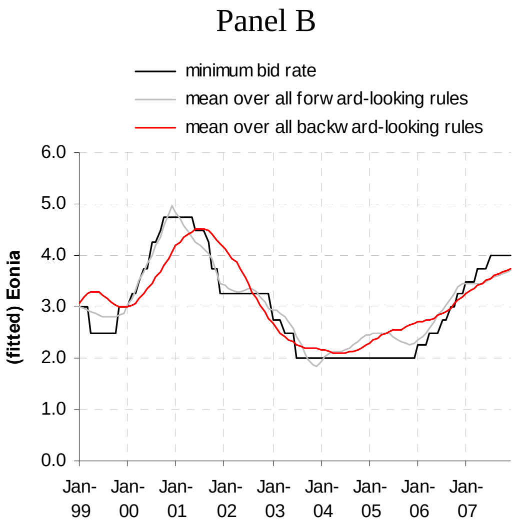
Table 3 (replicated). Mean estimates of policy rules for the euro area: thick-modelling (1999 to 2007)
(stand. errors in brackets; all coefficients statistically significant at least at the 10% confidence level)

	No of rules	Share of total	ρ	r^*	β_π	β_y	SEE	R^2
All rules	291		0.92	-0.53	1.25	0.94	0.2007	0.9562
			(0.03)	(0.37)	(0.46)	(0.19)		
Forward-looking in inflation and output	48	16.5%	0.91	-1.06	2.22	1.05	0.2002	0.9564
			(0.03)	(0.39)	(0.81)	(0.15)		
Backward-looking in inflation and output	117	40.2%	0.92	-0.20	0.55	0.82	0.2006	0.9562
			(0.03)	(0.36)	(0.18)	(0.2)		
Mixed rules	126	43.3%	0.91	-0.64	1.52	1.00	0.2010	0.9560
			(0.03)	(0.39)	(0.58)	(0.18)		

For convenience we replicate Table 3 with the results of the thick-modelling exercise here again. As becomes apparent from Table 7 only six of the nine possible combinations of inflation and output growth groups have passed the filters of Section III.1. In particular, the first principal component of the current year inflation projections group could never be identified as being statistically significant in estimations with any of the output growth groups. To a certain extent, this result confirms the findings of the thick-modelling exercise where only nine per cent of all finally selected rules contained an inflation indicator of this group (cf. Table 4). Several other similarities and differences with respect to the thick-modelling exercise become apparent. First, while the inflation coefficient in factor-based rules is on average below unity, purely forward-looking rules are still characterised by significantly larger inflation coefficients than other rules. Second, similar observations hold also true for the coefficient on output growth. It is about half the size in the factor-based rules as compared to the thick-modelling exercise, but its characteristics across different specifications do not change. Third, the standard errors of all estimated coefficients are substantially lower as compared to the results presented in Section III. This reflects the fact that factor-based rules only react to the large drifts in the data and not to the peculiarities of single indicators. This result is also consistent with the forecasting power ascribed to factor models (see Stock and Watson 1999). Finally, large differences emerge with respect to the estimated real interest rate.[35] In factor-based rules the natural rate is estimated to be in the neighbourhood of around three per cent, which is substantially larger than the slightly negative rates that were identified in the thick-modelling approach. This confirms the large degree of uncertainty surrounding the proper identification of the real interest rate.

Figure 7. Fitted values of the estimated factor-based policy rules

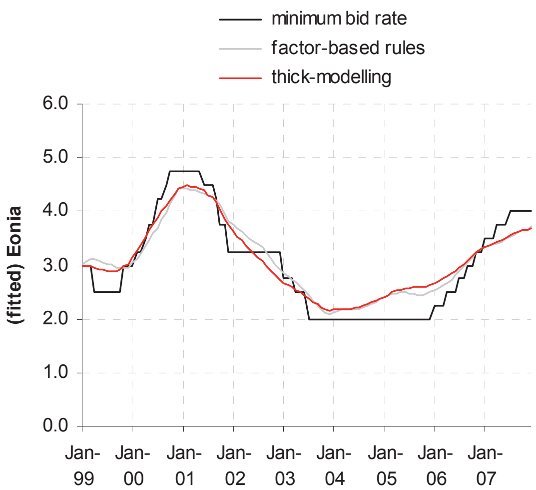




[35] We did not change the methodology of identifying the real interest rate. Given that the first principal components were restandardised prior to the estimations, the same inflation means were taken to approximate the inflation objective (see section III.2).

Figure 7 plots the minimum bid rate together with the fitted values for the EONIA rate implied by the estimates of the factor-based policy rules reported in Table 7. Similar to the thick-modelling exercise, the mean factor-based rule closely resembles the ECB's actual interest-rate decisions. The narrower corridor relative to the thick-modelling exercise mainly stems from the fact that the disperse information coming from the various indicators has been condensed to fewer factors *prior* to the estimation. The qualitative results, however, are similar. The only period in which policy-makers have deviated from the recommendations borne from estimated factor-based rules relates to the exceptionally long phase of low policy rates in 2005. Contrary to the thick-modelling exercise, some differences emerge with respect to the prescriptions coming from backward- and forward looking rules respectively. While the latter seem to resemble very closely the ECB's past policy decisions, in particular the tightening and loosening cycles between 2000 and 2004, backward-looking factor-based rules recommend, on average, a somehow smoother and at times lagged interest rate path relative to actual policy-making.

Figure 8. A comparison of the thick-modelling and the factor-based approach



Finally, we want to compare the overall fit of the thick-modelling exercise with the factor-based approach (see Figure 8). The similarity between the two approaches in terms of fit is striking. Both methods lead to virtually identical prescriptions for the policy rate in the euro area. This result underlines the mutual power of the thick-modelling and factor-based approaches in terms of their ability to substantially compress both the degree of information coming from the variety of indicators and the uncertainty surrounding the recommendations borne from estimated policy reaction functions based on a single indicator.

V. Conclusion

The economic literature has witnessed the appearance of a wealth of research directed towards describing the historical pattern of monetary policy. A standard practice of the majority of the existing research in this field has been the reliance on a few economic indicators for modelling the conduct of monetary policy making. Such an approach involves not only an unjustifiably high degree of subjective judgement concerning which measures of macroeconomic developments are "truly relevant" for monetary policy makers but also grossly and unrealistically ignores the vast range of economic indicators that are constantly monitored by central banks.

The objective of this paper was to address this issue for the euro area using a new comprehensive real-time database that takes duly into account the informational rigidities that policy-makers face. We offer two powerful approaches towards dealing with the potential misspecification of econometric monetary policy models: thick modelling and factor extraction. Our thick modelling approach aims at exploring the robustness of the estimated euro area policy reaction function by considering an exhaustive set of combinations of measures of real economic activity and inflation. After applying a strict set of efficiency criteria for selecting the final set of estimated policy reaction functions, we find that almost 300 estimated rules are able to closely approximate the ECB's past interest-rate setting behaviour in a meaningful statistical and economic way. This finding constitutes a stark warning for the possible deep misspecifications that can result from conditioning the evolution of monetary policy on only a small set of economic indicators. We also find that the ECB is neither purely backward nor forward-looking, but reacts to a synthesis of the available information on the current and future state of the economy.

In our second approach to dealing with the issue of model uncertainty – factor extraction – we partition our real-time data set into subgroups of similar macroeconomic concepts. We extract factors with a precise structural meaning and link monetary policy decisions to changes in these structurally identifiable factors.

The major conclusions reached under our factor-based approach largely mirror the results reached under our thick modelling exercise. In particular, we show that bundling the large information set that policy-makers are exposed to *prior* to the estimation lead to virtually the same prescriptions for the policy rate as compared to the thick-modelling exercise.

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Annex 1. List of output and inflation measures used in the estimations

Table A1. 1 List of output growth indicators (in alphabetical order):

Factor[36]	Indicator
P	Consumer confidence (EC, change w.r.t. last GovC meeting)
P	Consumer confidence (EC, change w.r.t. 3 months before)
P	Domestic demand (qoq, latest available figure)
P	Domestic demand (qoq, latest available figure-1)
P	Domestic demand (qoq, latest available figure-2)
P	Domestic demand (qoq, latest available figure-3)
P	Domestic demand (qoq, average of 4 latest available figures)
P	Domestic demand (yoy, latest available figure)
P	Domestic demand (yoy, latest available figure-1)
P	Domestic demand (yoy, latest available figure-2)
P	Domestic demand (yoy, latest available figure-3)
P	Domestic demand (yoy, average of 4 latest available figures)
P	Economic slack (Domestic demand (yoy) - real GDP (yoy))
P	Economic slack (Domestic demand (qoq) - real GDP (qoq))
P	Foreign annual GDP growth forecast (US,JP,UK)
P	Foreign annual industrial production growth forecast (US,JP,UK)
P	Net Exports (qoq, latest available figure)
P	Net Exports (qoq, latest available figure-1)
P	Net Exports (qoq, latest available figure-2)
P	Net Exports (qoq, latest available figure-3)
P	Net Exports (qoq, average of 4 latest available figures)
P	Net Exports (yoy, latest available figure)
P	Net Exports (yoy, latest available figure-1)
P	Net Exports (yoy, latest available figure-2)
P	Net Exports (yoy, latest available figure-3)
P	Net Exports (yoy, average of 4 latest available figures)
P	Gross Fixed Capital Formation (qoq, latest available figure)
P	Gross Fixed Capital Formation (qoq, latest available figure-1)
P	Gross Fixed Capital Formation (qoq, latest available figure-2)
P	Gross Fixed Capital Formation (qoq, latest available figure-3)
P	Gross Fixed Capital Formation (qoq, average of 4 latest available figures)
P	Gross Fixed Capital Formation (yoy, latest available figure)
P	Gross Fixed Capital Formation (yoy, latest available figure-1)
P	Gross Fixed Capital Formation (yoy, latest available figure-2)
P	Gross Fixed Capital Formation (yoy, latest available figure-3)
P	Gross Fixed Capital Formation (yoy, average of 4 latest available figures)
FC	Gross Fixed Capital Formation forecast current year (Consensus)
FN	Gross Fixed Capital Formation forecast next year (Consensus)
P	Industrial production (yoy)
P	Industrial production confidence (EC, change w.r.t. last GovC meeting)
P	Industrial production confidence (EC, change w.r.t. 3 months before)
FC	Industrial production forecast (Consensus, yoy rate prevailing one year ahead)
FC	Industrial production forecast current year (Consensus, yoy)
FN	Industrial production forecast next year (Consensus, yoy)
P	Labour productivity (yoy)

[36] P: Past output growth; FC: Current year forecast; FN: Next year forecast.

P	Private consumption expenditure (qoq, latest available figure)
P	Private consumption expenditure (qoq, latest available figure-1)
P	Private consumption expenditure (qoq, latest available figure-2)
P	Private consumption expenditure (qoq, latest available figure-3)
P	Private consumption expenditure (qoq, average of 4 latest available figures)
P	Private consumption expenditure (yoy, latest available figure)
P	Private consumption expenditure (yoy, latest available figure-1)
P	Private consumption expenditure (yoy, latest available figure-2)
P	Private consumption expenditure (yoy, latest available figure-3)
P	Private consumption expenditure (yoy, average of 4 latest available figures)
FC	Private consumption forecast current year (Consensus)
FN	Private consumption forecast next year (Consensus)
P	Real GDP (qoq, latest available figure)
P	Real GDP (qoq, latest available figure-1)
P	Real GDP (qoq, latest available figure-2)
P	Real GDP (qoq, latest available figure-3)
P	Real GDP (qoq, average of 4 latest available figures)
P	Real GDP (yoy, latest available figure)
P	Real GDP (yoy, latest available figure-1)
P	Real GDP (yoy, latest available figure-2)
P	Real GDP (yoy, latest available figure-3)
P	Real GDP (yoy, average of 4 latest available figures)
FC	Real GDP growth forecast (Consensus, yoy rate prevailing one year ahead)
FC	Real GDP growth forecast current year (AMECO)
FC	Real GDP growth forecast current year (Consensus)
FC	Real GDP growth forecast current year (ECB)
FC	Real GDP growth forecast current year (IMF)
FC	Real GDP growth forecast current year (OECD)
FC	Real GDP growth forecast current year (SPF)
FN	Real GDP growth forecast next year (AMECO)
FN	Real GDP growth forecast next year (Consensus)
FN	Real GDP growth forecast next year (ECB)
FN	Real GDP growth forecast next year (IMF)
FN	Real GDP growth forecast next year (OECD)
FN	Real GDP growth forecast next year (SPF)
P	Retail sales confidence (EC, change w.r.t. last GovC meeting)
P	Retail sales confidence (EC, change w.r.t. 3 months before)
P	Retail sales volume (yoy)
P	Total employment growth (yoy)
P	Unemployment rate (change w.r.t. last GovC meeting)
P	Unemployment rate (change w.r.t. 3 months before)
FC	Unemployment rate forecast cur. year (Consensus, change w.r.t. last GovC meeting)
FC	Unemployment rate forecast cur. year (Consensus, change w.r.t. 3 months before)
FN	Unemployment rate forecast next year (Consensus, change w.r.t. last GovC meeting)
FN	Unemployment rate forecast next year (Consensus, change w.r.t. 3 months before)

Table A1. 2 List of inflation indicators (in alphabetical order):

Factor[37]	Indicator
P	Break-even inflation rate (French indexed bonds)
P	Compensation per employee (yoy)
FC	Consumer price forecast (Consensus, yoy rate prevailing one year ahead)
FC	Consumer price forecast current year (AMECO)
FC	Consumer price forecast current year (Consensus)
FC	Consumer price forecast current year (ECB)
FC	Consumer price forecast current year (IMF)
FC	Consumer price forecast current year (OECD)
FC	Consumer price forecast current year (SPF)
FN	Consumer price forecast next year (AMECO)
FN	Consumer price forecast next year (Consensus)
FN	Consumer price forecast next year (ECB)
FN	Consumer price forecast next year (IMF)
FN	Consumer price forecast next year (OECD)
FN	Consumer price forecast next year (SPF)
P	HICP (yoy) - consumer goods (durables)
P	HICP (yoy) - consumer goods (non-durables)
P	HICP (yoy) - consumer goods (total)
P	HICP (yoy) - energy prices
P	HICP (yoy) - headline
P	HICP (yoy) - non-energy industrial goods
P	HICP (yoy) - processed food
P	HICP (yoy) - services
P	HICP (yoy) - unprocessed food
P	Industrial producer prices (yoy) - capital goods
P	Industrial producer prices (yoy) - intermediate goods
P	Industrial producer prices (yoy) - manufacturing goods
P	Industrial producer prices (yoy) - total (excl. construction)
P	Oil price (1-month ahead delivery in EUR, change w.r.t. last GovC meeting)
P	Oil price (1-month ahead delivery in EUR, change w.r.t. 3 months before)
P	Oil price (Brent in EUR, change w.r.t. 3 months before)
P	Oil price (Brent in EUR, change w.r.t. last GovC meeting)
P	Oil price (Brent in USD change w.r.t. 3 months before)
P	Oil price (Brent in USD, change w.r.t. last GovC meeting)
P	Unit labour costs (yoy)
FC	Wage growth forecast current year (Consensus, yoy)
FN	Wage growth forecast next year (Consensus, yoy)

[37] P: Past inflation; FC: Current year forecast; FN: Next year forecast.

Annex 2. Distribution of standard errors of the estimated coefficients

Figure A2.1 Standard errors of the smoothing coefficient

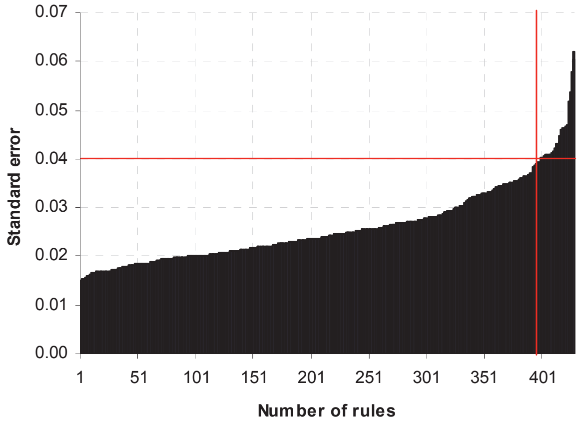

Figure A2.2 Standard errors of the constant

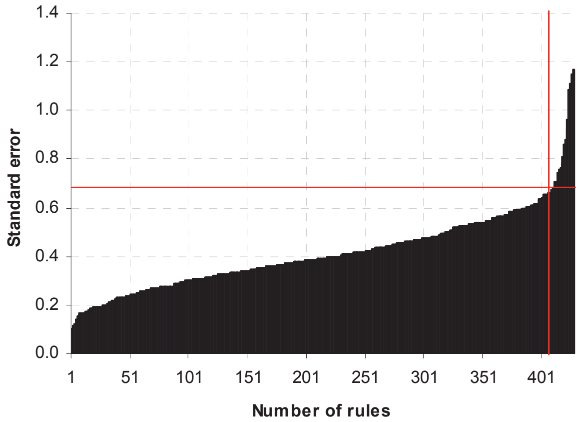

Figure A2.3 Standard errors of the inflation coefficient