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Empirical similarity for revealing the US interest rate policy: modeling case-based decisions of the FOMC

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Abstract
We model the Fed's decisions about interest rate adjustments via the flexible nonlinear empirical similarity (ES) concept which relies on ideas of case-based reasoning particularly suitable for decision making under uncertainty. We postulate that the Fed's adjustment decision in a given situation should be close to those in similar economic situations. We evaluate the empirical fit of the ES concept in comparison with the linear reaction function related to the Taylor rule for the period from 1987 till 2008. We identify and analyze critical time points particularly for those Fed decisions which were conducted in rather uncertain economic environments.

Keywords Taylor rule · Empirical similarity · Case-based reasoning

1 Introduction

Central banking is often called an Art rather than a Science (Hawtrey 1932; De Grauwe 2002). The main reason for this is seen in the fact that central banking is plagued by fundamental uncertainty about the importance of various transmission channels, about the response of the public to announcements and actions of a central bank, and about the effectiveness of the central bank's instruments in general. It is often argued that the lack of solid knowledge about macroeconomic relationships and transmission channels of monetary policy limits the extent to which central banking can be based on science alone (cf. Mishkin 2010).

In order to assess central bank decision rules in a more formal way, starting from the 1990 s there were major developments both in monetary theory (Clarida et al. 1999) and in understanding the practice of central banking (Blinder 2004). The famous Taylor rule is a prominent example of a simple and easy-to-communicate linear reaction function (LRF) for interest rate adjustments (cf. Taylor 1993, 1999). Various specifications and refinements of the original Taylor rule have been proposed (among others) by Clarida

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et al. (1999), Boivin (2006) and Coibion and Gorodnichenko (2011). Moreover, there is a substantial recent empirical literature on nonlinear Taylor rules: Alcidi et al. (2011) estimate a nonlinear policy rule via a logistic smoothing transition regression; Bae et al. (2012) evaluate a Markov-switching model for a Taylor-type policy rule for the Fed; Gnabo and Moccero (2015) estimate regime switching models where the response of monetary policy to macroeconomic conditions depends on the risk level the economy is facing. According to many scholars, these developments contributed much to a better formalization of central bankers' policy.

Yet even proponents of the scientific approach admit its limitations, as it must be complemented by judgment and intuition of central bankers (see De Grauwe 2002). The prime example of a central banker with supposedly superior judgment and intuition is Alan Greenspan who was often called "maestro" or "magician," even though with hindsight his performance may be less glorious than seen by some at the end of his chairmanship (Blinder and Reis 2005). The time of Greenspan's reign is of special interest to study as it was a rather long period from 1987 until 2006 with many distinguished events such as crises and recessions. Taylor (2012) reports that even under Greenspan's chairmanship the Fed's monetary policy from 1985 to 2003 is well described by a simple LRF that does not require any notion of judgment. However, according to Taylor and other studies, the Fed's policy after 2003 have deviated from the Taylor rule.

Remarkably, Greenspan himself never subscribed to a simple policy rule as the only guidance for monetary policy. In Greenspan (2004) he argues that monetary policy makers are permanently confronted with fundamental uncertainty about their environment so that formal economic models are only of limited use for practical policy because they cannot always accommodate structural changes in the economy. He makes clear that a simple Taylor rule with inflation and output gap as targets is not incompatible with his monetary policy approach and that (under some circumstances) the Taylor rule can describe policy decisions of the Federal Open Market Committee (FOMC) quite well. However, judgment and discretionary decisions are especially relevant at "crucial points", at which it is necessary to assess economic conditions and potential risks more broadly than implied by simple rules and economic models. Hence, Greenspan vehemently rejects the notion that the policy under his chairmanship was determined by simple formal rules.

The challenge to assess the role of judgment and intuition in decision-making process is that they are difficult to observe and hard to describe formally. To address this task, we suggest to evaluate judgments in monetary policy-making by exploiting the cased-based decision theory (CBDT) of Gilboa and Schmeidler (1995, 2001). Thinking-by-analogy CBDT principles amend those of rule-based reasoning for decisions in situations where formal rules are hard to apply. Without specifying formal rule-based models, the empirical similarity (ES) approach of Gilboa et al. (2006) allows to reveal the mechanism behind case-based decisions directly from the data.

Instead of claiming that interest rate decisions can be described by a fixed rule, we argue that it would be desirable to model the decision-making process in a more flexible way. We believe that case-based decision theory could be suitable to model the use of judgment and experience by central bankers. CBDT describes reasoning by analogy where the decision maker compares the current decision situation with other cases and chooses that action that works best in similar cases. Applied to monetary policy this means that the central bank chooses an interest rate adjustment that is similar to those under economic conditions (described by some explanatory variables) that are most similar to the current. Those cases could be ones that the decision maker actually experienced previously, or even hypothetical cases which the decision maker just imagines. These hypothetical cases imply a mental model of the decision maker, which she might not be able to specify explicitly. Identifying unique crucial points that do not fit to the usual patterns on which central bankers base their decisions might help to comprehend these implicit mental models better.

In this paper we propose how to use the ES approach in order to explain the Fed's interest rate adjustments. Our historical empirical similarity (HES) modeling suits for learning the principles behind the FOMC's interest rate decisions directly from the data. Moreover, we aim at identifying crucial points which are distinct from routine situations of policy-making and which require expert judgement by the central bankers. Understanding monetary policy particularly at crucial points is immensely important both from a practical perspective and for the further development of monetary theory and models of monetary policy. Our approach contributes also to this strand of literature, because we do not only propose a novel empirical approach, but also relate it to the CBDT that helps formalizing the notions of risk management and judgment in central banking. This theoretical framework might be useful for a better integration of the theory and practice of monetary policy-making.

We contrast the HES approach with the LRF for explaining FOMC decisions concerning interest rate adjustments during 1987–2008. The similarity of economic situations is assessed based on inflation expectations, output growth, and the output gap, which also enter the LRF as explanatory variables (cf. Coibion and Gorodnichenko 2011). We show that in the full sample the HES and LRF models provide a comparable statistical fit. Moreover, the HES is much better suited for explaining interest rate adjustments starting from 2003 where—according to the conjecture of Taylor (2012)—the Fed has changed the policy from rule- to case-based. We interpret these results as evidence that the HES amends rule-based models in situations when the latter are hard to justify. Next, we classify all situation by their pairwise similarity by means of a cluster analysis applied to the HES estimates. We identify four clusters corresponding to the distinct phases of the business cycle, as well as several "orphans" which are special (unique or seldom) cases not belonging to any cluster. The further analysis of these special cases shows that the HES approach appears to be extremely useful for exploring the reasons of these orphans' uniqueness, and, hence, for a better understanding of the FOMC's decision principles.

The paper is organized as follows. In Sect. 2, we describe US central banking during the Great Moderation with a special emphasis on how Greenspan understood his task. In Sect. 3, we discuss case-based decision theory and provide the empirical similarity concept as a data-driven model of interest rate adjustment decisions. In Sects. 4 and 5, we describe the empirical specification, the data used, as well as the estimation procedure and the empirical results. Section 6 concludes.

2 FOMC during the great moderation

In this paper, we analyze the US Fed's monetary policy in the period from August 1987 until December 2008, which roughly corresponds to the so-called Great Moderation period of low output volatility and low inflation in the USA. This period is also a distinct era in the history of US monetary policy, because it is the time during which Alan Greenspan was the chairman of the Federal Open Market Committee (FOMC). Greenspan served as the chairman from 1987 until 2006 and was praised at that time as "being the greatest central banker who ever lived" (Blinder and Reis 2005). With hindsight this assessment is controversial, because Greenspan's policy was blamed for having caused or at least contributed to the following subprime mortgage financial crisis (e.g., Taylor 2012). It is not our intention to settle the question of how good or bad Greenspan's monetary policy especially in the early 2000 s was. We want to use this particular period as an illustrative case for our theoretical and empirical approach to understand the interest rate decisions that the Fed made.

Additionally to Greenspan's era, we also include two years of Bernanke's chairmanship from 2006 to 2008 in order to extent the time span up to the outbreak of the subprime financial crisis. For this time interval Taylor (2012) postulated a conjecture about a change of monetary policy principles around 2002. On the contrary, we argue that the period between the chairmanship of Paul Volcker and the financial crisis in 2008 could be seen as a period characterized by a more or less coherent framework for monetary policy. Before Bernanke succeeded Greenspan as the chairman of the FOMC, he was a member of the board of governors from 2002–2005. It was Bernanke who popularized the term "Great Moderation" and argued in a widely regarded speech at the 2004 meetings of the Eastern Economic Association[1] "that good monetary policy of the Fed was an important explanation for it". Apart from the Great Moderation, two aspects make this period especially interesting: an extensive description of Greenspan's understanding of monetary policy and literature on the Taylor rule.

Based on Greenspan's own description of his conception of monetary policy, Blinder and Reis (2005) emphasize that his policy framework is one of risk management as opposed to optimization approaches that are tightly connected to economic models. According to Greenspan (2004)

"policymakers often have to act, or choose not to act, even though we may not fully understand the full range of possible outcomes, let alone each possible outcome's likelihood. As a result, risk management often involves significant judgment as we evaluate the risks of different events and the probability that our actions will alter those risks. [...] For such judgment, policymakers have needed to reach beyond models to broader, though less mathematically precise, hypotheses about how the world works. For example, inferences about how market participants and, hence, the economy might respond to a monetary policy initiative may need to be drawn from evidence about past behavior during a period only roughly comparable to the current situation."

[1] www.federalreserve.gov/BOARDDOCS/SPEECHES/2004/20040220/default.htm.

The Greenspan standard appears to be in strong contrast to the idea of rule-based monetary policy according to which the central bank sets the interest rate rather mechanistically in response to changes in relevant macroeconomic variables. The most prominent examples of such rules are different versions of the Taylor rule that provide a good description of US monetary policy between 1987 and 1992. Linear Taylor rules can be derived from New Keynesian models which focus on the macroeconomic stabilization of output and the price level, also reflected in the dual mandate of central banks. Furthermore, the literature on central banks' credibility provide arguments for rule-bound monetary policy such that an easy-to-communicate rule seems to be attractive to anchor and manage the public's inflation expectations. A standard Taylor rule postulates (cf. Clarida et al. 2000) that the target nominal interest rate r_t is the linear function

$$r_t = r_t^* + \beta(E[\pi_{t,k}|\mathcal{F}_t] - \pi^*) + \gamma E[x_{t,q}|\mathcal{F}_t], \tag{1}$$

where $\pi_{t,k}$ denotes annualized %-change in the price level between periods t and $t+k$, π^* is the target for inflation, $x_{t,q}$ is a measure of the average output gap between period t and $t+q$, with the output gap being defined as %-deviation between actual GDP and the corresponding target. $E[\cdot|\mathcal{F}_t]$ is the conditional expectation where $\mathcal{F}_t$ is the information set at the time of decision; r_t^* is the desired nominal rate when both inflation and output are at their target levels. Note that t is not the calendar time here but the number of the Fed's meeting. It is generally acknowledged that linear Taylor rules are a decent statistical description of the Fed's monetary policy from 1985 to 2002, see Poole (2007). The choice of these 'target' variables is commonly communicated by central banks and also theoretically motivated from the perspective of New Keynesian models, for more details see, e.g., Clarida et al. (1999), Clarida et al. (2000) and Coibion and Gorodnichenko (2011).

Based on the ex-post analysis, Taylor (2012) argues that there was a major break in the Fed's monetary policy and that there are two different eras: the rule-based era from 1985 to 2003 and the ad-hoc era after 2003. In particular, the federal funds rate was much lower than the interest rate implied by the Taylor rule starting from around 2001. Furthermore, between 2002 and 2004 the federal funds rate and the Taylor rate moved much from each other. However, neither the good statistical fit before 2002/2003 does prove unambiguously that the Fed's monetary policy was rule-based at that time, nor does the later deviation deliver cogent evidence for a fundamental policy shift. In fact, Greenspan vehemently rejected the notion that the Fed's monetary policy under his reign was ever determined by simple formal rules. With respect to Taylor rules, Greenspan said in a speech[2] in 1997:

"Taylor-type rules or reaction functions have a number of attractive features. They assume that central banks can appropriately pay attention simultaneously to developments in both output and inflation, provided their reactions occur in the context of a longer-run goal of price stability and that they recognize that activity is limited by the economy's sustainable potential.

As Taylor has pointed out, these types of formulations are at best "guideposts" to help

[2] https://www.federalreserve.gov/boarddocs/Speeches/1997/19970905.htm.

central banks, not inflexible rules that eliminate discretion. One reason is that their formulation depends on the values of certain key variables—most crucially the equilibrium real federal funds rate and the production potential of the economy. In practice these have been obtained by observation of past macroeconomic behavior—either through informal inspection of the data, or more formally as embedded in models. In that sense, [...] they embody a forecast that the future will be like the past. Unfortunately, however, history is not an infallible guide to the future, and the levels of these two variables are currently under active debate."

Greenspan (2004) makes clear that a simple Taylor rule with inflation and output as targets is not incompatible with his monetary policy approach and that under some circumstances, the Taylor rule can describe policy decisions of the FOMC quite well. However, in an environment characterized by fundamental uncertainty, judgment and discretionary decisions are especially relevant at "crucial points", at which it is necessary to assess economic conditions and potential risks more broadly than implied by simple rules and economic models (cf. Greenspan 2004, p. 38–39):

"But at crucial points, like those in our recent policy history (the stock market crash of 1987, the crises of 1997–1998, and the events that followed Sept 2001), simple rules will be inadequate as either descriptions or prescriptions for policy."

That there was a shift in policy around 2002 seems to be the most plausible explanation for the evidence within the New Keynesian framework which considers inflation and output as the only targets of monetary policy and assumes a stable economic environment. However, these equilibrium models with a fixed structure and uncertainty represented by stochastic shocks may not be the best description of the economic environment as perceived by policy makers. As Greenspan (2004) argues, monetary policy makers are permanently confronted with fundamental uncertainty, so that formal models are only of limited use for practical policy because they not always provide a valid description of economic reality in a changing environment. Furthermore, for policy practitioners it is also clear that financial stability is always a goal of monetary policy, even if this is not as apparent as during and after the financial crisis of 2008 (Mishkin 2011). Hence, another explanation for the alleged structural break around 2002 is that there was a perceived shift in the economic environment in which decisions had to be made, rather than a fundamental reorientation of monetary policy itself.

The central research question of our paper is whether it is possible to formally describe monetary policy that is not based on simple rules but mostly characterized by judgment in crucial situations. Can we capture the reasoning of the FOMC and model its behavior in a more natural way than by simple Taylor rules? We claim that the answer is yes and that we can use case-based decision theory and its econometric implementation, the empirical similarity approach, for this purpose.

3 The empirical similarity approach

3.1 Case-based decision theory

Monetary policy makers are always confronted with fundamental uncertainty concerning both evaluation of the current situation and the choice of suitable actions. Gilboa and Schmeidler (1995) argue that the expected utility theory (EUT)—conventionally used in macroeconomic theory—is not appropriate for dealing with this kind of uncertainty as it does not describe plausible cognitive processes of decision makers: in order to be able to apply EUT, decision makers have to imagine all possible outcomes and all relevant states, and to attach probabilities and utility levels to them. In most macroeconomic situations, however, this is far too complex, since the number of states could be huge and the states themselves are typically not defined in an intuitive way. Furthermore, it is essentially impossible to assign probabilities reliably in many economic settings.

As an amendment to EUT, Gilboa and Schmeidler (1995, 2001) propose the case-based decision theory (CBDT) which is particularly suitable for decision making under uncertainty. They argue that in many situations people reason by drawing analogies between past cases and the one at hand, and choose acts based on their performance in similar problems in the past. Gilboa and Schmeidler (2001) define a case to be a triple of a problem, an act, and a result, whereby problems are descriptions of choice situations. An act is a decision that was or can be made, and a result is the outcome of a chosen act in a choice situation. The CBDT postulates that agents remember and compare current problems with similar problems that they or other agents encountered in the past. Specifically, the CBDT axiomatizes a model in which each act is selected by maximization of the weighted sum of utility outcomes over all possible acts, with the weights reflecting the similarity of the current and experienced cases.

We argue that the CBDT could suggest an appropriate way to model the use of judgment and experience by central bankers. CBDT describes reasoning by analogy (cf. Gilboa et al. 2014): the decision maker compares the current decision situation with past ones and chooses that action that worked best in similar cases in the past. Applied to monetary policy this means that the central bank would adjust an interest rate similarly to adjustments in cases in which economic conditions (e.g., the phase of the business cycle) were most similar to the present. Those cases could be ones actually experienced in the past or some hypothetical cases which the central banker could imagine or reconstruct. These hypothetical cases imply a mental model of the central banker, which could be difficult to specify in a form of particular decision rules.

Making decisions by analogy does not imply that this approach is completely a theoretical, as it requires a theoretical conception to determine what a case is and which variables to look at for similarity assessment. Obviously, there are many economic theories or models that postulate links between interest rates, the rate of inflation and output. So already choosing inflation and the output gap as characteristics of a situation or case suggests that the decision maker has some theory or model in mind. However, in contrast to a rigid decision rule which is derived from a particular model, similarity considerations are quite flexible and robust against model misspecification. The major difference is that rules can be refuted by cases whereas cases are not contradicted but amended by other cases (Gilboa et al. 2014, p. F518). Basically, CBDT says that a decision which delivers good results in a similar situation should be also a good decision in the case at hand. Since it does not necessarily predict the result to be identical, a surprising outcome of a decision will not immediately question the decision's theoretical basis. In a world with considerable fundamental uncertainty, this feature is rather appealing for decision makers.

Further, we would like to emphasize that the CBDT should not be considered as irrational or boundedly rational. It is far from clear how rational decision making should look like in a world characterized by ambiguity or even fundamental uncertainty. If probabilities, or model parameters, or even structural relationships between variables are unknown, the conventional optimal-control approach of minimizing expected loss functions is not applicable. As Gilboa and Schmeidler (2001, p. 105) put it:
"We maintain, however, that normative theories should be constrained by practicality. Thus, it is far from clear that, in complex problems for which past data are scarce, case-based decision making is any less rational than EU-maximization."

3.2 The empirical similarity approach

Now we formalize the empirical similarity (ES) approach which allows to estimate the mechanism described by CBDT with econometric toolkits. Consider a p-dimensional vector of variables $\mathbf{x}_t$ characterizing the current situation (or problem) and y_t is the relevant (scalar) decision variable to choose which describes the act. In the following we distinguish between notions of "situation" and "case". A "case" refers to case-based decision theory and includes the problem, as well as the act and the outcome. A "situation" is the empirical equivalent to a "case", but does not contain the act and the outcome. The set $\{\mathbf{x}_t, y_t\}$ formally denotes a case at time t, which should be compared to other cases characterized by the sets $\{\mathbf{x}_s, y_s\}$ for all $s \neq t$. The original ES approach of Gilboa et al. (2006) provides the econometric framework for cases based only on history with $t > s$.

Yet it seems unrealistic to assume that central bankers only use rather limited number of previously experienced cases as the basis of their decisions. A more realistic setting is to assume that they have mental models that enable them to imagine how they would act in this or that situation. In order to reveal this mental model, one should apply all available data points. For this purpose, Gayer et al. (2007) introduce the historical empirical similarity (HES) approach with $s \neq t$ which implies the following model equation:

$$y_t = \sum_{s \neq t} \psi_{ts} y_s + \varepsilon_t = \sum_{s \neq t} \psi[\mathbf{x}_s, \mathbf{x}_t] y_s + \varepsilon_t, \qquad \varepsilon_t \sim \text{iid}(0, \sigma^2). \tag{2}$$

In HES the current value of the choice variable is represented as a weighted sum of historical (i.e., past and future) process realizations. The weight $\psi_{ts} = \psi[\mathbf{x}_s, \mathbf{x}_t]$ measures the similarity between situations at t and s which is the distance between the vectors $\mathbf{x}_t$ and $\mathbf{x}_s$ as it is assessed by decision makers. Thus, the weights $\psi_{ts} \in [0, 1]$ can be interpreted as normalized relative empirical similarities with the property $\sum_{s \neq t} \psi_{ts} = 1$.

To complete the HES specification, we write the similarity weights as

$$\psi_{ts} = \psi[\mathbf{x}_s, \mathbf{x}_t] = \frac{\theta[\mathbf{x}_s, \mathbf{x}_t]}{\sum_{j \neq t} \theta[\mathbf{x}_j, \mathbf{x}_t]}, \quad \text{for} \quad t \neq s, \tag{3}$$

where $\theta[\mathbf{x}_s, \mathbf{x}_t] \geq 0$ is the similarity (distance) function. For computational convenience, we also set $\psi_{ts} = 0$ for $t = s$, i.e., for the case of self-similarity. There are several possibilities to postulate the functional form of the similarity function $\theta[\mathbf{x}_s, \mathbf{x}_t]$ (cf. Lieberman 2010). We exploit a flexible exponential similarity function motivated by Billot et al. (2008):

$$\theta_{ts} = \theta[\mathbf{x}_s, \mathbf{x}_t] = \exp\left(-\sum_{i=1}^{p} \omega_i (x_{i,s} - x_{i,t})^2\right), \qquad i = 1, ..., p, \tag{4}$$

where $(\omega_1, ..., \omega_p)$ are unknown non-negative parameters to be estimated.

For the interpretation of the similarity function θ_{ts} note that a small distance $\sum_{i=1}^{p} \omega_i (x_{i,s} - x_{i,t})^2$ would lead to a high similarity value of θ_{ts}. That means, the ES concept contains information about which variables should be similar/close at t and s so that the situations at t and s are considered as similar/close.

4 Empirical models, data and estimation

Now we describe the models, in particular, the LRF as well as our implementation of the HES approach for the analysis of how the FOMC set interest rates during the Great Moderation period. The main idea of our research strategy is to check whether the HES model has a potential to uncover the actual reasoning behind the FOMC's interest rate decisions. We argue that case-based reasoning with making decisions by analogy in an uncertain environment might be a good theoretical approach to reveal the Fed's decision principles that is based on judgment and known as the "art of central banking". The obtained estimates for similarity measures would tell us which macroeconomic situations described by a set of economic variables $\mathbf{x}_t$ are similar from the perspective of the FOMC and, hence, could be used for justifying similar interest rate decisions.

4.1 Linear reaction function (LRF)

First we consider the LRF of the Fed which grounds on the Taylor rule and is a natural benchmark for our purposes. We follow Coibion and Gorodnichenko (2011) who derive an empirical specification of the LRF given as:

$$r_t = \phi_0 + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \sum_{i=1}^{3} \phi_i x_{i,t} + u_t, \qquad u_t \sim \text{iid}(0, \sigma^2), \tag{5}$$

where r_t is the nominal interest rate which is the central object of our interest. Due to the usual interest rate smoothing policy of the central banks (cf. Woodford 2003) the interest rates are strongly autocorrelated which justifies the inclusion of the lagged interest rates into Eq. (5). In this LRF the central bank is assumed to respond to three macroeconomic variables: the expected rate of inflation $x_{1,t}$, the expected growth rate of output $x_{2,t}$ and the expected output gap $x_{3,t}$.

The model in (5) provides a valid econometric specification for the Taylor rule decision principles. The New Keynesian literature uses the so-called linear-quadratic framework where the linear optimal policy rules are derived for a quadratic loss function of the central bank given linear constraints. However, the linear-quadratic modeling approach is criticized by Mishkin (2010) as being inadequate for modeling the nonlinearities that play an important role, e.g., during financial crises. Although the time-constancy of the parameters in models like (5) is questioned (cf. Boivin 2006), Coibion and Gorodnichenko (2011) show that these simple linear regressions are useful to explain the Fed's interest rate adjustments at least during 1987–2002. Their evidence is in line with Taylor (2012) who argues that the Fed's policy could be well-explained by a linear Taylor rule until 2002, but not after that time. Taylor concludes that the Fed seemed to change its policy so that the rule-based era was over, an ad-hoc era started where the Fed's policy appears to be less predictable and rather case-oriented.

The empirical analysis shows that the interest rate process r_t is nearly integrated of order 1, i.e., it is quite close to non-stationarity as $\rho_1 + \rho_2 \lesssim 1$ (cf. Coibion and Gorodnichenko 2011). As this is hardly distinguishable from the unit root process in finite samples and complicates the estimation of the model in (5), we immediately consider the process in first differences defined as $\Delta r_t = r_t - r_{t-1}$. Namely, we estimate the following LRF with all variables in % changes

$$\Delta r_t = \phi_0 + \sum_{i=1}^{3} \phi_i x_{i,t} + \epsilon_t \quad \text{or} \quad \Delta r_t = \phi_0 + \boldsymbol{\phi}' \mathbf{x}_t + \epsilon_t. \tag{6}$$

Modeling the reaction function in the first differences is also appealing apart from econometric and statistical reasons. The public typically pays a lot of attention to the size and direction of changes in the interest rate and central bank communication, hence, focuses on explaining the adjustment rather than the level.

4.2 Empirical similarity model

Even though there is evidence that LRFs based on the Taylor rule describe the Fed's behavior during the 1990 s quite well, Greenspan himself never admitted to follow a Taylor rule. For this reason we propose an alternative ES-based approach which relies on CBDT principles for modeling the Fed's interest rate adjustments during Greenspan's reign. In particular, we analyze whether the HES model is able to explain the Fed's policy both before and after 2003 when the LRF broke down.

Our HES modeling grounds on the assumption that by making case-based decisions of the interest rate, the central bank[3] constructs a linear combination (weighted average) of all experienced adjustments in past or future situations with the weights determined by similarity of these (past or future) economic conditions to the current situation. To formalize this idea, consider the central bank which should decide on the interest rate adjustment Δr_t given the vector of explanatory variables $\mathbf{x}_t$ which describes the current economic situation and contains—as also for the LRF—the expected rate of inflation $x_{1,t}$, the expected growth rate of output $x_{2,t}$ and the expected output gap $x_{3,t}$.

It seems unrealistic to presume that central bankers just rely on past experiences when judging a situation. We rather assume that they also have a mental model of the economy even if this model cannot be formalized by external observers. We, hence, adopt the historical empirical similarity (HES) approach in which the central banker may know in advance how they would react in various (hypothetical) situations. In particular, in the HES the size and sign of the adjustment Δr_t is specified as a linear weighted combination of all adjustments $\Delta r_s, s \neq t$, where the weights are determined depending on the distances between $\mathbf{x}_t$ and $\mathbf{x}_s$. Then the HES reads as

$$\Delta r_t = \sum_{s \neq t} \psi_{ts} \Delta r_s + \epsilon_t, \qquad \epsilon_t \sim \text{iid}(0, \sigma^2), \qquad t, s = 1, ..., T. \tag{7}$$

The normalized weights ψ_{ts} with $\psi_{ts} \in [0, 1]$ and $\sum_{s \neq t} \psi_{ts} = 1$ form a $T \times T$ (not necessarily symmetric) matrix $\Psi = (\psi_{ts})$ with zeros of the main diagonal, see the sentence after (3). This matrix summarizes the information about relative similarity of $\mathbf{x}_t$ with $\mathbf{x}_s$, $s \neq t$. The HES model in (7) can be written as

$$\Delta r_t = \psi_{t1} \Delta r_1 + \cdots + \psi_{t\,t-1} \Delta r_{t-1} + \psi_{t\,t+1} \Delta r_{t+1} + \cdots + \psi_{t\,T} \Delta r_T + \epsilon_t,$$

so that the expected adjustment $E[\Delta r_t]$ should be close to those Δr_s-values which are done in situations similar to the situations in t.

In order to illustrate the flexibility of the HES model, one could imagine as a special case the point similarity (cf. Lieberman 2010) for $\Delta r_t \approx \Delta r_\tau$ in case of $\psi_{t\tau} \approx 1$ and $\psi_{ts} \approx 0$ for $s \neq t$ and $s \neq \tau$, where only two situations are really similar to each other. Another special case is a uniform similarity with $\psi_{ts} = 1/(T-1)$ so that $\Delta r_t = 1/(T-1) \cdot \sum_{s \neq t} \Delta r_s$, where one could hardly discriminate situations with respect to the selected explanatory variables $\mathbf{x}_t$.

The similarity weights $\psi_{ts} \in (0, 1)$ are defined for all $s \neq t$ as a weighted distance between the elements of economic variable vectors $\mathbf{x}_t$ and $\mathbf{x}_s$ as in (3) and (4). The similarity matrix $\Theta = (\theta_{ts})$ with $t, s = 1, \ldots, T$ contains non-normalized distances as they are perceived by decision makers. The matrix Θ is a correlation-type symmetric matrix with ones on the main diagonal and non-negative off-diagonal elements. In our empirical study we use the estimated $\widehat{\Theta}$ to find similar time points in the assessment of the Fed directly from the data by applying the correlation clustering analysis.

[3] More precisely, the actor is not the central bank but the FOMC, or, potentially, even Alan Greenspan during that time, if his decisions were believed to determine in essence the decisions of the whole FOMC.

4.3 Research strategy, data and estimation method

Relying on the HES approach, our research strategy covers two major issues. First, we estimate both the LRF in (6) and the HES model in (7), and compare them with respect to their statistical fit to the data. Then, we perform a kind of cluster analysis of the information contained in the estimated similarity matrix $\widehat{\Theta}$ that reveals which situations characterized by the explanatory variables are perceived by the Fed as similar. This second step would help us to uncover the implicit Fed's mental model as well as how the Fed interpreted the economic environment during those years.

From the literature, we know already that the LRF has a good fit from 1987 until about 2002. The interesting question is what happened in the time around 2002. Was there really a major policy shift as claimed by Taylor (2012) in the sense that the LRF describes the Fed's behavior before 2002 but not afterward? To investigate this issue in more detail, we split our sample into a first period till 2002 and a second one from 2003. If the Taylor's conjecture were correct, we should observe that the LRF would fit the data much better in the first period than in the second one. However, if the HES model has a fit that is at least as good as the fit of the LRF, we argue that the former should be preferable, since it is more in line with Greenspan's statements about his way of conducting monetary policy.

We investigate the interest rate adjustments using the data covering the period from 1987 to 2008. Then the Federal funds rate has been basically zero for a long period of time and the monetary policy regime was clearly different so that we do not use data from the time after 2008. Our dataset is based on the Fed's Greenbook and is an extension of those used by Coibion and Gorodnichenko (2011) until the end of 2008. We estimate the models for the full sample as well as for two subperiods from August 1987 to December 2002, and from January 2003 to December 2008. The dates of the subperiods are selected in line with Taylor (2012), who argues that the ad-hoc era started as the (Taylor) rule era ended in 2002. A structural break analysis of the LRFs based on the classical Chow test as well as online monitoring procedures (cf. Golosnoy et al. 2012; Golosnoy and Hogrefe 2013) supports this division of the sample. The dynamics of the interest rate adjustments Δr_t and of the explanatory variables over the considered periods is visualized in Fig. 1, with the summary statistics reported in Table 1. Interest rate adjustments are strongly correlated with output growth, exhibit medium correlation with the output gap and only weak correlation with inflation, both for the full sample and for the subsamples.

5 Empirical results

5.1 Comparison of LRF and HES models

Here we present the estimation results for the LRF and HES models, respectively. The consistency of the maximum likelihood estimation of ES models is shown by Lieberman (2010), however, we estimate the parameters ω_i in the similarity function $\theta[\mathbf{x}_t, \mathbf{x}_s]$ by the nonlinear least squares (NLS) approach because of the computational stability arguments (cf. Golosnoy et al. 2014, 2022). Note that using the NLS provides

Table 1 Descriptive statistics for interest rate adjustments Δr_t, inflation x_1, output growth x_2, output gap x_3

period (# obs.)	1987–2002 (123)				2003–2008 (47)				1987–2008 (171)			
statistic	Δr_t	$x_{1,t}$	$x_{2,t}$	$x_{3,t}$	Δr_t	$x_{1,t}$	$x_{2,t}$	$x_{3,t}$	Δr_t	$x_{1,t}$	$x_{2,t}$	$x_{3,t}$
min, %	−1.00	0.95	−3.10	4.60	−1.25	−1.80	−4.70	−3.10	−1.25	−1.80	−4.70	−4.60
max, %	0.75	5.10	5.30	3.10	0.25	5.90	5.00	0.60	0.75	5.90	5.30	3.10
mean, %	−0.044	2.60	2.22	−0.196	−0.021	1.83	2.53	−0.843	−0.037	2.38	2.31	−0.386
st.dev., %	0.312	0.924	1.60	2.00	0.337	1.20	1.91	1.05	0.318	1.06	1.69	1.81
$Corr(\Delta r_t, x_{i,t})$	1	0.07	0.62	0.28	1	0.08	0.69	0.10	1	0.06	0.64	0.23
1st lag autocorr	0.47	0.93	0.86	0.97	0.64	0.59	0.76	0.95	0.52	0.96	0.86	0.97
2nd lag autocorr	0.41	0.87	0.73	0.94	0.36	0.31	0.64	0.88	0.40	0.93	0.73	0.93

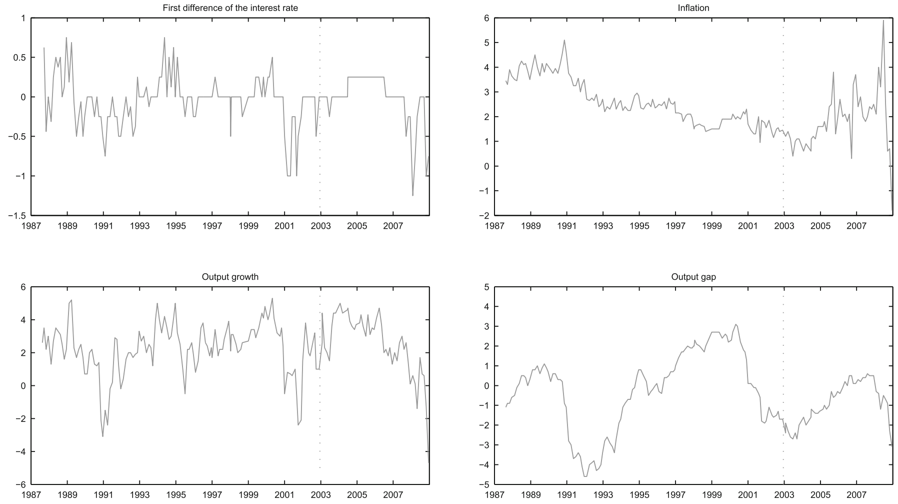

Fig. 1 Time series of Δr_t, inflation $x_{1,t}$, output growth $x_{2,t}$, output gap $x_{3,t}$

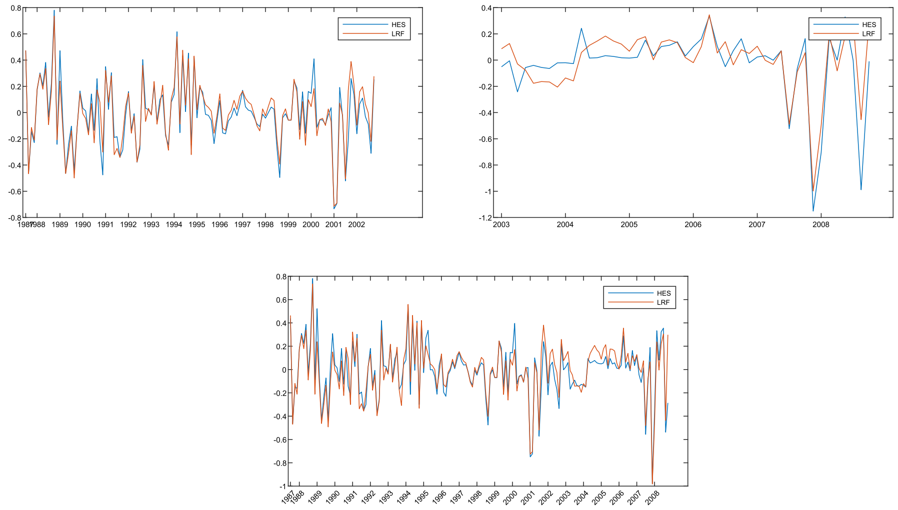

Fig. 2 LRF (red) and HES (blue) residuals for 1987–2002, 2003–2008, 1987–2008

the same point estimates as the maximum likelihood in the case of $\epsilon_t \sim \text{iid}\, \mathcal{N}(0, \sigma^2)$, however, leads to different standard errors (cf. Seber and Wild 2003). The HES and OLS-based LRF estimation results, as well as some model diagnostics are summarized in Table 2, whereas model residuals are plotted in Fig. 2.

The LRF has a decent fit for the first period 1987–2002, see the upper panel of Table 2. The adjustment coefficients of the federal funds rate are significant for inflation and for output growth, however, the coefficient for output gap is insignificant.[4] The fit

[4] In Coibion and Gorodnichenko (2011) the expected output gap is significant, but their sample begins already in 1983. Furthermore, they estimate the model in levels instead of first differences.

Table 2 HES and LRF parameter estimates

1987–2002	Const	Inf	Ogrowth	Ogap	σ^2	R^2	R^2-adj	AIC	AR1	LB5	KS
HES w_i		0.835**	0.924***	0.508**	0.062	0.371	0.355	−582.6	0.046	0.81	0.35
st.dev		0.343	0.259	0.247							
LRF	−0.475***	0.062**	0.122***	0.009	0.058	0.418	0.403	−588.9	0.087	0.52	0.77
st.dev	0.077	0.024	0.015	0.012							
2003–2008	const	inf	ogrowth	ogap	σ^2	R^2	R^2-adj	AIC	AR1	LB5	KS
HES w_i		0	2.266***	4.452***	0.041	0.657	0.642	−194.9	−0.133	0.28	0.00
st.dev		–	0.417	0.747							
LRF	−0.320***	0.007	0.122***	0.027	0.062	0.490	0.455	−173.1	0.263	0.13	0.08
st.dev	0.110	0.037	0.019	0.042							
1987–2008	const	inf	ogrowth	ogap	σ^2	R^2	R^2-adj	AIC	AR1	LB5	KS
HES w_i		0.995***	1.051***	0.449***	0.059	0.420	0.410	−876.1	0.091	0.67	0.28
s.d		0.177	0.186	0.172							
LRF	−0.414***	0.041**	0.123***	0.005	0.058	0.434	0.424	−876.9	0.137	0.11	0.26
st.dev	0.056	0.018	0.012	0.011							

HES and LRF parameter estimates with st. deviations, R^2, R^2-adjusted and Akaike Information criterion (AIC) measures, the 1st order residual autocorrelation (AR1), p-values for 5-lags Ljung-Box (LB5) and Kolmogorov–Smirnov (KS) normality tests on residuals of the HES model in this period is slightly inferior with the adjusted $R^2 = 0.355$, but is quite close to that of the LRF with the adjusted $R^2 = 0.403$. All HES variables ω_i are significantly different from zero which supports the assumption that the FOMC seemed to use at least these variables to evaluate the economic conditions.

The estimates of the HES parameters ω_i are not straightforward to interpret. In general, large values of ω_i imply that even small differences between $x_{i,t}$ and $x_{i,s}$ lead to a low similarity θ_{ts} of situations at time t and s. Hence, we can say that the increase of weight ω_i makes the ith explanatory variable more important for FOMC to distinguish economic situations. For 1987–2002 the output growth parameter is the largest (0.924) in the HES, followed by those for inflation (0.835) and output gap (0.508). This order is similar to the estimates for the LRF. Since all x-variables are measured as %, we can compare the magnitudes of the coefficients directly. However, the marginal effect meaning of the LRF coefficients is very different from the meaning of the HES coefficients. For example, in the LRF, an increase in output growth of 1% always leads to an increase of the expected interest rate by 0.122%, given the values of the expected inflation and of output gap. This does not hold for the HES model where an increase of the expected growth rate of 1% only leads to a certain assessment of the similarity of situations with that growth rate. The HES interest rate decisions, however, depend not only on the similarity of situations but also on interest rate adjustments made in these situations.

The middle panel of Table 2 contains the estimation results for the second subperiod 2003–2008 whereby two findings are especially noteworthy. First, the HES model has a much better statistical fit than the LRF in that period with the adjusted R^2 of 0.642 versus 0.455, respectively. It is very remarkable that for several dates in this period, the HES residuals are exactly zero as shown in the middle panel of Fig. 2. Second, the LRF has the even higher adjusted R^2 after 2002 compared to the previous subperiod (0.403). This result is very interesting, because it contradicts the claim that Taylor-rule-like policy functions only fit the data until 2002 and that there was a major shift from rule-based policy to ad-hoc policy in 2002. We do not want to make a strong case for the argument that the Fed's monetary policy was rule-based in either of the two periods. Yet if one claims that the Fed's policy was based on simple rules before 2003 based on the good statistical fit of linear reactions functions, one certainly has to assume the same for the time after 2002 given our estimation results.

In the period 2003–2008, the HES and LRF lead to different conclusions on what drove the FOMC's interest rate adjustments. Both models imply that the impact of inflation was not significantly different from zero, which is not surprising as inflation was rather low at that time.[5] According to the LRF, the interest rate adjustments mostly depend on expected output growth with the same coefficient as before. In the HES model the output growth parameter is also significant, but so is the parameter for the output gap. The weight of the output gap 4.452 is much larger than the weight on output growth 2.266, which suggests that the FOMC paid a lot of attention to the shortfall of output from its potential. This finding is consistent with the public debate of the

[5] As the HES point estimate of the inflation parameter ω_1 is very close to zero, we fix it to $\omega_1 = 0$ in order to get numerically stable standard errors.

so-called jobless recovery after the 2001 recession (Aaronson et al. 2004; Schreft and Singh 2003).

The estimates for the full sample 1987–2008 are shown in the bottom panel of Table 2. The adjusted R^2 indicates that both models have a similar statistical fit: 0.419 (HES) and 0.433 (LRF). The LRF estimates are close to those from the first subsample 1987–2002. The point estimates of the output growth coefficients are almost identical (0.125 vs. 0.122), the inflation coefficient is a bit smaller in the full sample (0.055 vs. 0.062), and the output gap's coefficient is also not significantly different from zero. The fact that the adjusted R^2 is higher in the full sample than the pre-2003 sample sheds more doubt on the hypothesis that LRFs only suit to the data until 2002. In the HES, only output growth and output gap are significant with estimates a bit larger than those from the pre-2003 subsample. The full sample HES weight of inflation is not significantly different from zero. While the irrelevance of inflation for the Fed's decisions might seem surprising, it is supported by its low correlation with interest rate changes, see Table 1. Both models show similar full sample fit, however, the HES residuals are much closer to zero than the LRF residuals in 2004–2006, see Fig. 2.

Although R^2 (or R^2-adjusted) is the most common measure for performance evaluation of linear models, some other criteria are also advocated for the performance evaluation of nonlinear models (cf. Spiess and Neumeyer 2010). For this reason we additionally report in Table 2 the Akaike information criterion (AIC) which is known to be a suitable performance measure in the context of least squares estimation (cf. Banks and Joyner 2017). The AIC results fully support the evidence from R^2 measure, namely, the LRF has a lower AIC (i.e., is better) for the first subsample 1987–2002, whereas the HES has a lower AIC for the second subsample 2002—2008. In the full sample the AIC values for the HES and LRF are almost equal. This is an indicator for the robustness of the obtained empirical findings.

We conclude that both LRF and HES can describe the Fed's interest rate adjustments quite well during the period 1987–2008 from a purely statistical perspective. Yet we argue that the HES model is preferable, since it has more plausible theoretical underpinnings, selects—differently to the LRF—the output gap as the FOMC's key indicator,[6] and performs better in the period after 2002.

5.2 Cluster analysis of the similarity weights

Using the estimated weights $\hat{\omega}_i$ and the variables $x_{i,t}$ and $x_{i,s}$ we compute the HES weight estimates $\hat{\theta}_{ts}$ that indicate the perceived similarity between any two dates t and s as implied by the Fed's interest rate adjustments. A cluster analysis of the similarity weights $\hat{\theta}_{ts}$ would reveal whether there are periods or phases consisting of several dates that can be seen as economically similar in the FOMC's judgement. For our purposes we apply the correlation clustering algorithm as in Bansal et al. (2004) with the tiny values $< 10^{-3}$ replaced by zeros. The non-classified observations are denoted as "orphans". The colored clusters are shown in Fig. 3.

[6] As also in the New Keynesian framework (cf. Clarida et al. 1999), where the target variables in the policy objective function are the output gap and the inflation gap.

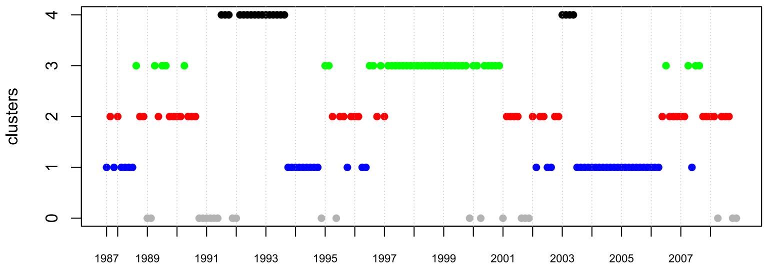

Fig. 3 HES clusters of similar situations, min 12 obs. per cluster

The cluster analysis on the full sample with a minimum of 12 observations per cluster[7] identifies four distinct clusters (blue, red, green, and black points) and a set of "orphan" observations (gray circles) that do not belong to any cluster. Figure 3 shows these clusters: a blue cluster (phase 1), a red cluster (phase 2), a green cluster (phase 3), a black cluster (phase 4), and the gray orphans which are not part of a cluster (phase 0). It is immediately apparent from Fig. 3 that all four clusters are spread over the sample period. The black cluster stands out, because it is concentrated to two periods: 1990:8–1993:9 and 2003:1–2003:6. It is also remarkable that the majority of the orphan dates belong to the three NBER recessions in the sample period: November 1990–July 1991, September 2001–November 2001, December 2007–June 2009. Those orphans at the end of the sample also coincide with the start of the subprime mortgage financial crisis.

In order to get a better understanding of how the clusters should be interpreted, we calculate the means of the rate of inflation, the expected growth rate of output and the expected output gap for each cluster shown in Table 3. Confirming the visual impression from Fig. 3, orphans belong to situations with low output growth and large output gap. During these recessionary or even crisis periods, strong downward adjustments of the interest rate took place. In the blue cluster, inflation is low, the output gap is moderate, but output growth is strong. In a business cycle terminology, we could hence speak of a recovery. In this case the central bank usually responds by raising the interest rate. The red cluster contains downturn periods with weak growth, high inflation and moderate output gap. Then a common monetary policy is expansionary. The green cluster is similar to the blue cluster with low inflation and high growth, but has large positive output gap. The monetary policy stance in that phase is neutral. The main feature of the black cluster is the very large negative output gap which is even larger (cf. Table 3) than during the recessions. At the same time output growth and inflation are moderate. Note that both black clusters occur relatively shortly after two NBER recessions when the "jobless recovery" phenomenon was discussed in the news media (Aaronson et al. 2004). The Fed responded to these situations with slightly expansionary monetary policy.

Next, we also analyze how the selected explanatory variables are related to the explored HES clusters. Our previous analysis shows that inflation rate does not matter much within the HES model in the full sample. The boxplots in Fig. 4 illustrate no clear pattern with respect to inflation across the clusters. In the orphan periods the

[7] Setting at least 10 or 15 observations per cluster leads to very similar results.

Table 3 Cluster means of economic variables

Cluster	# Obs	Inf	Ogrowth	Ogap	r	Δr_t	Phase description
0 (orphans)	21	2.75	0.14	−1.32	4.97	−0.28	Recessions/crisis/crucial points
1 (blue)	45	2.11	3.71	−0.83	3.64	0.19	Recovery
2 (red)	42	2.65	1.34	−0.14	5.15	−0.18	Downturn
3 (green)	43	2.17	2.87	1.65	5.88	0.01	Expansion
4 (black)	20	2.36	2.18	−3.31	3.08	−0.11	Sluggish (jobless) recovery

Clusters with at least 12 observations per cluster

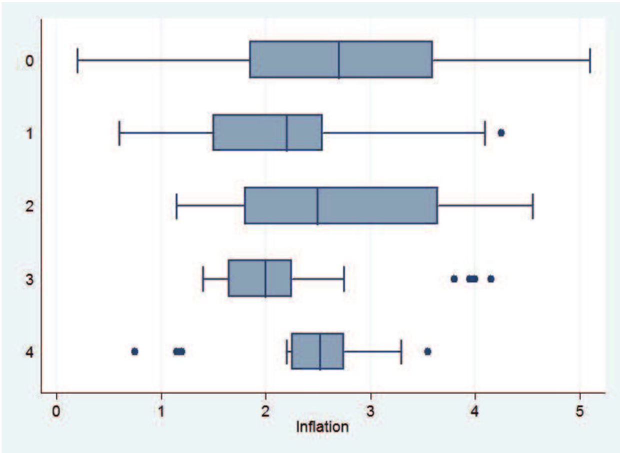

Fig. 4 Boxplots of inflation for 1987–2008 by different clusters

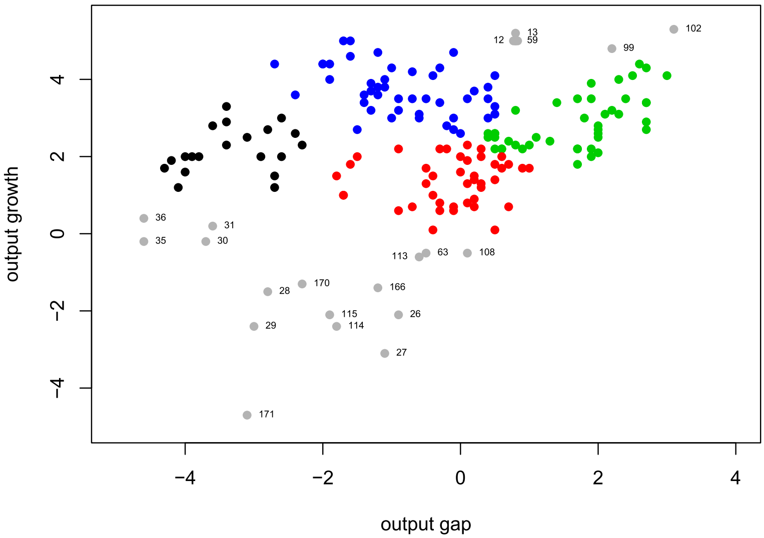

Fig. 5 Classifying economic cases with respect to output growth (y-axis) and output gap (x-axis)

inflation's variation is the largest. As there is a considerable overlap of boxplots for all clusters, it is hardly possible to distinguish them based on inflation.

Since inflation does not characterize the clusters, we depict them in output gap—output growth space in Fig. 5. The orphans, which are marked by gray circles, refer either to the region of the negative output growth or, in five very special cases, to very high output growth and positive output gap. However, as they mainly correspond to very different (primarily non-positive) values of the output gap, it is rather difficult to form a cluster from them. All four observed clusters correspond to the positive output growth, whereby the green cluster (expansion) stays for positive output gaps and the

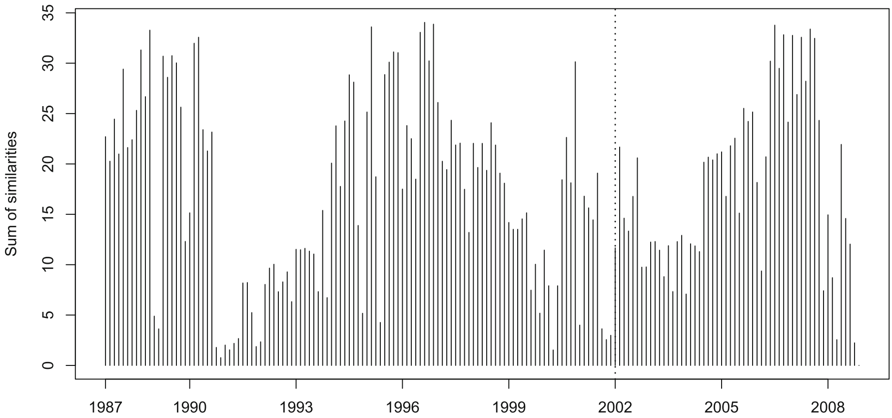

Fig. 6 Time series of representativeness measure $\widehat{\Theta}_t = \sum_{s \neq t} \hat{\theta}_{ts}$

black cluster (jobless recovery) for negative output gaps. The red (downturn) and blue (recovery) clusters unite situations with similar output gaps, however, the former corresponds to much lower (positive) output growth than the latter. This classification with regard to output gap and growth confirms our qualitative description of the results in Table 3.[8]

Now we explore what the HES model tells us about similarity of each case to others. For this purpose we introduce a convenient summary measure for the representativeness (or uniqueness) of each case at t, defined as the sum of the (non-normalized) similarity weights $\widehat{\Theta}_t = \sum_{s \neq t} \hat{\theta}_{ts}$. In Fig. 6, we show that $\widehat{\Theta}_t$ varies substantially over time, i.e., some cases with large $\widehat{\Theta}_t$ are very similar to many others and, hence, correspond to rather representative situations which occur more often. Alternatively, situations at dates t with a small representativeness $\widehat{\Theta}_t$ are seldom or even unique.

The representativeness clearly differs across the clusters as we show in Table 4. Almost by definition the orphan cases are quite unique. Their mean of $\widehat{\Theta}_t$ equals 1.83 and the maximal value is only 2.76. The blue, red, and green clusters have similar representativeness with the means of $\widehat{\Theta}_t$ between 14.7 and 15.0. The black cluster (corresponding to the jobless recovery period) is again quite different, because the average representativeness of 7.36 is less than half the mean value in the other clusters. Table 4 reveals another interesting characteristic of the black cluster: it is much more compact than the other clusters with the range $\max \widehat{\Theta}_t - \min \widehat{\Theta}_t = 4.24$, compared to the ranges of other clusters 12.69, 13.88, and 14.79. We interpret this evidence for the black cluster as the indicator that the situation in 2002—where according to Taylor the Fed has changed the policy—was quite similar to those in 1991 where the black cluster occurs for the first time in our sample.

Remarkably, the similarity within the clusters is not just determined by cases that are close in time dimension, i.e., within a time series model. In order to investigate the impact of temporal closeness, we look at the similarity weights in a time window

[8] Note that Greenspan was often sceptical about the output gap, because it is not easy to measure. However, he talked about its importance, especially in his later years.

Table 4 Summary statistics of representativeness $\widehat{\Theta}_t$ for each cluster

Cluster	Orphans (0)	Blue (1)	Red (2)	Green (3)	Black (4)
# Obs	21	45	42	43	20
Min $\widehat{\Theta}_t$	0.002	6.73	7.42	7.47	5.25
Max $\widehat{\Theta}_t$	2.76	19.42	21.30	22.26	9.49
Mean of $\widehat{\Theta}_t$ within the cluster	1.83	14.86	14.96	14.78	7.36
Mean $\widehat{\Theta}_t$ within ± 6 months	0.78	3.22	2.51	3.54	2.87

of six month before and after each date. As expected, we observe almost no temporal persistence for the orphans with the mean value of $\widehat{\Theta}_t$ within ± 6 months window equal to 0.78. Although the temporal persistence for all four clusters is much higher than for orphans with the mean value of $\widehat{\Theta}_t$ within ± 6 months ranging from 2.51 to 3.54, it is still much lower than even the minimal $\widehat{\Theta}_t$ in each cluster ranging from 5.25 to 7.47. This evidence illustrates the idea of the HES approach which is designed to find similar situations within the full sample.

5.3 Case studies of crucial points

We argue that the HES model enables a better description of the Fed's behavior than simple LRFs, because it is based on a behavioral theory that is well suited for decision making under uncertainty. We have shown that the LRF and HES models are comparable in terms of statistical fit, and that the HES generates plausible results with regard to how the FOMC assesses similarity of different phases of the business cycle. Another particular strength of the HES is that it helps to identify unique (special) cases that are perceived as not being similar to other cases. In these "crucial points" (cf. Greenspan 2004, p. 38–39)—judgement is of particular importance. Now we look on some of these crucial points more in detail.

In Table 5, we summarize 22 cases with the lowest representativeness ($\widehat{\Theta}_t < 6$) whereby 21 correspond to the orphan observations and one belongs to the black cluster. These cases can be united into five groups with at least two consecutive cases: (I) 1989:02–1989:03, (II) 1990:11–1991:07, (III) 1991:11–1992:2, (IV) 2001:09–2001:12 and (V) 2008:10–2008:12, whereas the six remaining cases with observation numbers 59, 63, 99, 102, 108, 166 do not belong to any group. Three groups (II, IV, V) partly overlap with the NBER recessions. Moreover, they coincide with significant unique events such as the Gulf war I (II), the 9/11 terrorist attacks (IV), and the financial crisis with Bear Stearns-story and the collapse of Lehman Brothers (V). It is hence not surprising, but rather reassuring, that the HES model identifies these cases as unique. The remaining six unique cases that do not correspond to the NBER recessions are especially interesting, because they demonstrate the power of our approach to identify Fed's crucial points that are not obviously related to either recession or some extraordinary events. Now we discuss jobless recovery cases in (II) and (IV) whereas the analysis of other interesting cases is available on request.

We present the data for the group (II) in Table 6. The NBER recession ended in March 1991 which was also the time of the Gulf war I. By August 1991, economic growth had recovered but the output gap was still considerably negative. This case marks the beginning of the first black cluster characterized by a sluggish recovery after a recession. At the end of 1991 the output gap became even wider and growth dropped again such that December 1991 and February 1992 are orphan cases. For the FOMC there was considerable uncertainty how to evaluate the situation.

In November, Alan Greenspan said in the FOMC meeting (p. 25/26):[9]

[9] All further quotes are taken from the FOMC meeting transcripts available at: www.federalreserve.gov/monetarypolicy/fomc_historical_year.htm.

Table 5 Unique cases identified by HES

Group/obs	Date	$\widehat{\Theta}_t$	HES cluster	NBER recession	Special event
I/12	1989:02	4.89	Orphan	No	
I/13	1989:03	3.63	Orphan	No	
II/26	1990:11	1.79	Orphan	Yes	
II/27	1990:12	0.77	Orphan	Yes	
II/28	1991:02	2.02	Orphan	Yes	Gulf war I
II/29	1991:03	1.55	Orphan	Yes	Gulf war I
II/30	1991:05	2.19	Orphan	No	
II/31	1991:07	2.67	Orphan	No	
III/34	1991:11	5.25	Black	no	
III/35	1991:12	1.87	Orphan	No	
III/36	1992:02	2.34	Orphan	No	
59	1994:12	5.18	Orphan	No	
63	1995:07	4.27	Orphan	No	
99	1999:12	5.19	Orphan	No	
102	2000:05	1.53	Orphan	No	Dot-com
108	2001:01	4.00	Orphan	No	
IV/113	2001:09	3.64	Orphan	Yes	"9/11"
IV/114	2001:10	2.57	Orphan	Yes	
IV/115	2001:12	2.99	Orphan	No	
166	2008:04	2.56	Orphan	Yes	Bear stearns
V/170	2008:10	2.24	Orphan	Yes	Lehman
V/171	2008:12	0.002	Orphan	Yes	

Note: Identification by the lowest representativeness $\widehat{\Theta}_t$

"I think what we are dealing with clearly is an historical process that has very little in the way of counterparts in the post-World War II period. This is an old fashioned asset contraction. It is reflected most severely in the commercial real estate area, with obvious consequences in the financial [sector] as we discussed.... The consequence of all this is that we have seen... a major crippling of financial intermediaries, Obviously, the S&Ls are not lending: they're in trouble [as are] the commercial banks and insurance companies.... We knew all of this two, three, four months ago. We certainly knew it when the economy was coming out of the recession.... There was no question that the economy was coming back in July and August. It wasn't coming back in a huge surge, but [at a pace] consistent with the preposition that this overhang of disinflationary forces was not very potent. In the last several weeks it is beginning to appear that that conclusion may not be correct; it can be a wholly false phenomenon."

In December 1991 the growth rate was again negative. Greenspan interpreted this as (p. 29/30):

"The economy is dead [in the water]. It's not decelerating; we are not getting really major problems. It is true that industrial production is down in November and that, on the basis of the weekly data we are looking at, it probably is going to be down in

Table 6 Macroeconomic situation in 1991/1992

Obs	Date	Representativeness $\widehat{\Theta}_t$	Inf	Ogrowth	Ogap	Δr_t	Cluster
II/29	March 1991	1.55	3.6	−2.4	−3.0	−0.25	0 (orphan)
II/30	May 1991	2.19	3.25	−0.2	−3.7	−0.25	0 (orphan)
II/31	July 1991	2.67	3.25	0.2	−3.6	0.00	0 (orphan)
32	Aug. 1991	8.19	3.55	2.9	−3.4	−0.25	4 (black)
33	Oct. 1991	8.23	3.00	2.8	−3.6	−0.25	4 (black)
III/34	Nov. 1991	5.25	3.30	1.2	−4.1	−0.50	4 (black)
III/35	Dec. 1991	1.87	3.50	−0.2	−4.6	−0.50	0 (orphan)
III/36	Feb. 1992	2.34	2.70	0.4	−4.6	−0.25	0 (orphan)
37	March 1992	8.04	2.65	1.6	−4.0	0.00	4 (black)
38	May 1992	9.66	2.75	2.0	−3.9	−0.25	4 (black)
39	July 1992	10.04	2.65	2.0	−3.8	−0.125	4 (black)

December. We are clearly looking at some secondary inventory recession, which is not atypical of previous pauses in past economic recoveries. What is really extraordinary about this particular period is what Jerry mentioned: namely, that in the context of a period not really all that much different from a lot of pauses in the early stages of a recovery, we have had such a dramatic drop in consumer confidence that one would presume that something fundamental has really struck us. We are all puzzling about it and [...] no one really knows exactly what happened. But let me throw on the table a possible hypothesis based on an additional piece of evidence. ...
What has happened, I suspect, is that while the economy was coming back from the recession, it led to a willingness on the part of the average consumer to say essentially that it's coming back and that's okay. But as soon as the balance sheet pressures put the wringer on this recovery, I think there was an abrupt reconfirmation of their concerns about whether the long term is really out there. They observed increasingly that they are living in houses that are nowhere near the quality of those that their parents lived in, even though their parents may not have had the education or any of a number of other [advantages] they have had. And they are worried about the future. They ask: Where is it all going? This situation creates a very profound fear."

These quotes suggest that this period was not only marked by large uncertainty, but also by the impression of a new phenomenon, namely sluggish recovery after a recession. At this time, the notion of "jobless recovery" came up in the news media.[10]

The second period we observe the black cluster in our sample is from 2003:1 to 2003:6. In the January 2003 meeting, the FOMC members reported a sluggish recovery of the economy after the recession and expressed uncertainty about the causes of this sluggishness. As possible reasons a potential war against Iraq and the crisis in the large oil producer Venezuela were mentioned. Greenspan (p. 147) summarized this discussion as follows:
"All this raises the interesting issue as to what will happen if and presumably when the geopolitical risks are removed. Will we be looking at a bounceback as this particular risk is removed, or will we be shocked to find that the sluggishness is still there? I don't know any way to judge [...] the relative probability of those two potential outcomes [...] we may say that history suggests such and such, but we really can't assess with confidence the probability of the two events."

In March 2003, the USA and their allies invaded Iraq so that the uncertainty about the outbreak of war was resolved, yet the recovery remained sluggish until June. In the June meeting of the FOMC Vice President Stuart from the New York Fed compared the situation to the case of the sluggish recovery in the early 1990 s (p. 87): *"Businesses have become very disciplined about continually looking for ways to increase output with fewer workers, and they expect to continue that practice even as sales pick up later this year. For that reason we expect employment to significantly lag economic recovery—even more than was the case in the early 1990 s."*

Finally, in August 2003 output growth accelerated to 3.6%, but the output gap remained at a low level of −2.4%. The clustering procedure assigns only the first four cases in 2003 to the black cluster and the cases from August 2003 until mid-2006 to the blue cluster, but many FOMC members continued discussing the jobless recovery

10 www.investopedia.com/articles/economics/10/jobless-recovery-the-new-normal.asp.

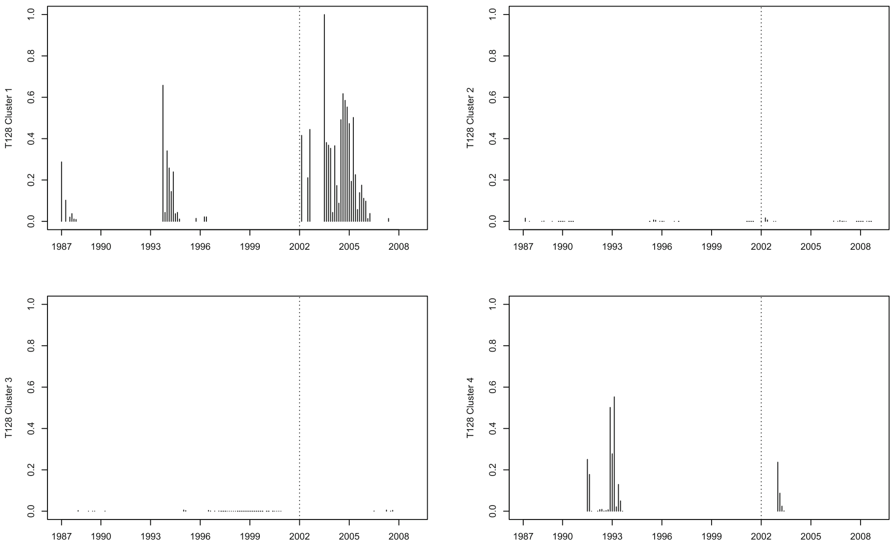

Fig. 7 Similarity of August 2003 (blue cluster 1) with other cluster, especially to black cluster 4

phenomenon even in the second half of 2003. In November 2003, Ben Bernanke, who was Governor of the Fed at that time, gave a speech on the jobless recovery[11] in which he compared the situation after 2001 with the 1990–1991 episode and mentioned structural changes in the economy as a potential reason for them.

To illustrate this evidence, we show in Fig. 7 the similarities $\hat{\theta}_{ts}$ for $t = 128$ (August 2003) sorted by clusters. We observed that while August 2003 is assigned to the blue cluster (1) instead of the black cluster (4), this case is also similar to the black clusters in the early 1990 s and in the first half of 2003, but not to any other cases in other clusters. As argued above, jobless recovery was a dominant theme both in the early 1990 s and in 2003 primarily characterized by the labor market dynamics and by the evolution of productivity. The HES approach reveals these commonalities. In sum, by our selected case studies we demonstrate that the HES model that builds on the analogy principles of CBDT is helpful to identify crucial points for monetary policy and situations that were considered similar by the members of the FOMC.

6 Summary and outlook

In this paper we propose a new approach to modeling and understanding monetary policy of central banks. In line with what many central bankers communicate, the conduct of monetary policy is at least as much an art as a science and often requires considerable intuition and judgement. Many situations are plagued by uncertainty and the lack of unambiguous data, but decisions must be made anyway. Our approach builds on case-based decision theory (CBDT) that formalized decision making by

[11] https://www.federalreserve.gov/BoardDocs/Speeches/2003/200311062/.

analogy which is applicable for uncertain environments. The empirical similarity (ES) approach allows to apply the theory to empirical data.

We apply the ES approach for explaining the Fed's decisions during the Greenspan era of the US monetary policy. This period is particularly suited because it is a comparatively long time under the same chairman. Greenspan postulated a specific approach to monetary policy-making in which he stressed the role of intuition and judgement especially at "crucial points" when formal models are of not much help. The Greenspan era is also of interest because it comprises both a number of recessions and periods of turbulence, but also longer spells of stability.

We show that our historical empirical similarity (HES) model has an empirical fit that is comparable to the often demonstrated good fit of linear reaction functions (LRFs) such as the Taylor rule in this period. Since the HES model is grounded on a more plausible theory of economic behavior under uncertainty than the rigid LRFs, we argue that it could be a better description of how monetary policy is actually conducted. LRFs might be interpreted as the first order approximations of the nonlinear true underlying data generating process.

Another advantages of the HES model is that it allows to compute empirical measures of similarity between cases. We show that based on these similarity measures all observed cases can be assigned to four clusters that correspond to phases of the business cycle, whereby some cases are classified as orphans which belong to no cluster. The gained clusters are mainly defined by the growth rate of output and the output gap, the role of inflation expectations is much less important. Even more interesting, the model also identifies unique cases that resemble only very few other cases. These orphan cases typically occur in time of high uncertainty. Uncertainty is high during recessions, but also at some other time point, e.g., at the upper turning point of the business cycle as in the mid-1990 s. The HES model also detects the two periods of sluggish or jobless recovery after the 1990/91 recession and in 2003 (labeled by a black cluster in our analysis), which sparked considerable debates both in public and among members of the FOMC about its potential causes.

We complement our econometric analysis with a number of case studies in which we identify important topics of discussion in the FOMC meetings using the meeting transcripts. These case studies corroborate that the orphan cases detected by the HES are indeed different from other cases and characterized by perceived uncertainty about the adequate monetary policy decisions. Statements of Greenspan and other FOMC members make clear that they often saw these cases as distinct from normal situations.

Note that we started with a relevant but very restricted set of macroeconomic variables that is also used in other empirical studies as well as in the LRF. Reading the meeting transcripts it is evident that the FOMC considers a much broader range of variables, at least in certain situations. Incorporating other relevant variables such as data on employment, productivity, sentiment, or financial indicators as, e.g., measures of stock market volatility or macroeconomic uncertainty might significantly improve the fit of the HES model and also lead to a finer classification of the cases. All these points are left for future research.

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