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Deviations from Rationality – Essays on Inflation Perceptions and Expectations

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Deviations from Rationality - Essays on Inflation Perceptions and Expectations

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Preface

This thesis was written while I was an external Ph.D. student at the chair of Prof. Dr. Jan-Egbert Sturm at the KOF Swiss Economic Institute, ETH Zurich. I would like to thank Prof. Jan-Egbert Sturm for giving me the opportunity and encouragement to follow my research interests, while providing highly valuable feedback, which substantially improved my work. Furthermore, I would like to express my gratitude for the hospitality I experienced during the semester I spent at the KOF Swiss Economic Institute in Zurich.

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Hamburg, May 2011 *Lena Dräger*

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Summary of the Thesis

This thesis evaluates deviations from full rationality in the formation process of inflation perceptions and expectations. Following widespread empirical evidence that households' inflation perceptions and expectations are not formed rationally as in Muth (1961), the chapters in this thesis discuss alternative models for perceived and expected inflation both theoretically and empirically.

The first two chapters extend the sticky information model by Mankiw and Reis (2001, 2002, 2003, 2007). In a dynamic stochastic general equilibrium (DSGE) model with heterogeneous expectations, the degree of inattentiveness of economic agents as the choice between rational or sticky information becomes endogenous and time-varying. The model employs the switching mechanism by Brock and Hommes (1997) and includes aspects of rational inattention as in Sims (2003). In the empirical part of the thesis, the formation process of inflation perceptions and expectations is analyzed with survey data of households' inflation perceptions and expectations from the European Commission's 'Joint Harmonized EU Program of Business and Consumer Surveys'. While the third chapter tests for evidence of loss aversion and the availability bias as proposed by Kahneman and Tversky (1979) and Tversky and Kahneman (1973, 1981, 1991) regarding the formation of inflation perceptions, the fourth chapter analyzes the interrelation of perceived and expected inflation and the role of the media, in line with the agenda-setting theory by McCombs (2004).

The following main results are obtained: Firstly, numerical simulation of the DSGE model with endogenous sticky information suggests that agents form expectations on output and inflation in line with aspects of near-rationality as in Akerlof and Yellen (1985) and Akerlof et al. (2000), increasingly choosing costly rational expectations when the variance of the forecasted variable is high. While determinacy is found to depend solely on adherence to the Taylor principle, the analysis of second moments and impulse-response functions shows, however, that optimal monetary policy aiming at stabilizing the economy should also target the output gap. Secondly, allowing for feedback from

time-varying inattentiveness to the model solution in a recursive equilibrium simulation yields strong persistence in aggregate output and inflation. Furthermore, determinacy of the model now also depends on monetary policy targeting the output gap with a small coefficient. Thirdly, empirical results for a panel of 10 European economies propose evidence of loss aversion and the availability bias for the pre-Euro sample period. However, these effects are less clear-cut in the period after the Euro introduction, where the reference rate of inflation seems to have increased and a generally higher awareness of price changes in various goods categories is observed. Finally, the analysis of perceived and expected inflation in Sweden suggests that during periods of high and volatile inflation, feedback effects between perceived and expected inflation increase. Moreover, media effects become more important, which may potentially introduce a bias through an asymmetric effect of negative news on perceived inflation.

Zusammenfassung der Dissertation

Die vorliegende Dissertation befasst sich mit Erklärungen für Abweichungen von vollständiger ökonomischer Rationalität bei der Bildung von Inflationswahrnehmungen und -erwartungen. In der Literatur werden empirische Ergebnisse ausführlich diskutiert, die nahelegen, dass wahrgenommene und erwartete Inflationsraten nicht anhand der Rationalitätskriterien von Muth (1961) gebildet werden. In den einzelnen Kapiteln dieser Dissertation werden daher alternative Modelle für die Bildung von Inflationswahrnehmungen und -erwartungen sowohl theoretisch, als auch empirisch, überprüft und bewertet.

Die ersten beiden Kapitel erweitern das 'sticky information' Modell von Mankiw und Reis (2001, 2002, 2003, 2007). In einem dynamischen stochastischen allgemeinen Gleichgewichtsmodell (DSGE) mit heterogenen Erwartungen wird der Grad der Unaufmerksamkeit ökonomischer Agenten endogenisiert und zeitvariabel, indem die Agenten zwischen rationalen Erwartungen und solchen mit veralteter ('sticky') Information wählen können. Das Modell nutzt den Wechselmechanismus von Brock und Hommes (1997) und greift Aspekte der 'rational inattention' Theorie von Sims (2003) auf. Im empirischen Teil der Dissertation wird die Bildung von Inflationswahrnehmungen und -erwartungen anhand von Umfragedaten des 'Joint Harmonized EU Program of Business and Consumer Surveys' der Europäischen Kommission analysiert. Während das dritte Kapitel die Hypothesen von Verlustaversion und der Verfügbarkeitsheuristik, vorgestellt in Kahneman und Tversky (1979) sowie Tversky und Kahneman (1973, 1981, 1991), in Bezug auf wahrgenommene Inflation testet, analysiert das vierte Kapitel die Beziehung zwischen wahrgenommener und erwarteter Inflation sowie, in Anlehnung an die 'agenda-setting' Theorie von McCombs (2004), die Rolle von Medienberichten über Inflation.

Die wichtigsten Ergebnisse der Dissertation lassen sich wie folgt zusammenfassen: Erstens zeigt die numerische Simulation des DSGE-Modells mit endogener Unaufmerksamkeit, dass ökonomische Agenten im Modell Erwartungen bezüglich Output und Inflation anhand der Kriterien von 'near-rationality' aus Akerlof und Yellen (1985) und

Akerlof et al. (2000) bilden, wonach kostspielige rationale Erwartungen zunehmend gewählt werden, wenn die Varianz der prognostizierten Variablen steigt. Während die Bestimmtheit des Modells nur vom Taylor-Prinzip abhängt, zeigt die Analyse zweiter zentraler Momente und Impuls-Antwort-Folgen, dass eine optimale Geldpolitik auch auf Veränderungen im Output-Gap reagieren sollte. Zweitens erzeugen Simulationen, in denen sich die zeitvariable Unaufmerksamkeit ökonomischer Agenten rekursiv auf das Modellgleichgewicht auswirkt, eine hohe Persistenz in den simulierten Daten für aggregierten Output und Inflation. Außerdem ist für die Bestimmtheit des Modells nun auch entscheidend, dass die Zentralbank mit einem kleinen Koeffizienten auf den Output-Gap reagiert. Drittens zeigen die empirischen Ergebnisse für ein Panel mit 10 Europäischen Ökonomien, dass die wahrgenommene Inflation für den Zeitraum vor der Euro-Einführung Anzeichen von Verlustaversion aufweist und sich Effekte der Verfügbarkeitsheuristik zeigen. Dieser Effekt ist jedoch weniger eindeutig für den Zeitraum nach der Euro-Einführung, wo die Ergebnisse eine erhöhte Referenzinflationsrate und eine gestiegene Wahrnehmung von Preisänderungen im Allgemeinen zeigen. Viertens weist die Analyse von wahrgenommener und erwarteter Inflation in Schweden auf eine ausgeprägtere Wechselwirkung in Zeiträumen mit hoher und volatiler Inflation hin. Auch verstärkt sich in diesen Phasen die Wirkung von Medienberichten, so dass Inflationswahrnehmungen möglicherweise durch die asymmetrische Wirkung von negativen Zeitungsberichten verzerrt werden können.

Chapter 1

Introduction

1.1 Rationality in Macroeconomics

The importance of perceptions and expectations for economic decisions under uncertainty and incomplete information has long been recognized in economic theory. In his seminal contribution, Keynes (1936) stresses the importance of forward-looking expectations by firms regarding prices they can charge for goods produced in the future and the effect of firms' expectations on unemployment. From a microeconomic perspective, von Neumann and Morgenstern (1944) formalize individuals' choice process between uncertain outcomes in their expected utility theory.

This thesis contains four papers, which evaluate the formation process of inflation perceptions and expectations both empirically and theoretically. As a recurrent theme, all four papers analyze formation processes that extend the rationality proposition as in Muth (1961), either to account for rational deviations from full rationality or to include behavioral aspects that might influence the formation process. This approach is motivated, on the one hand, by the inability of contemporary macroeconomic models, namely New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models with rational expectations, to reproduce important stylized facts found in aggregate empirical data (Rudd and Whelan, 2005). These include the persistence of aggregate output and inflation and the delayed responses to a monetary policy shock (Fuhrer and Moore, 1995, Christiano et al., 2005, Rotemberg and Woodford, 1997). Chapters 2 and 3 present DSGE models with endogenous sticky information and heterogeneous expectations that attempt to mitigate these shortcomings. On the other hand, there exists strong empirical evidence for non-rationality of both inflation perceptions and expectations, see for instance Thomas (1999) for a survey. Testing for the rationality criteria of accuracy, unbiasedness and efficiency using survey data for a European sample and for Sweden, in chapters 4 and 5, rationality of both inflation perceptions and expectations is rejected.

The remainder of this chapter is structured as follows. This section presents a short historical overview of the emergence of rational expectations as one of the main building blocks of modern macroeconomics. Section 1.2 discusses a number of theories presenting rational or behavioral deviations from Muthian rationality that provide the theoretical underpinning of this thesis. The objectives and the outline of the thesis are then presented in section 1.3.

The notion of rational expectations was first presented in the seminal paper by Muth (1961). Proposed as an alternative to adaptive expectations predominantly assumed in macroeconomic models at the time, Muth (1961) defines rational expectations of firms as following the same distribution as the prediction of the economic theory. Thus, firms' subjective probability distribution of future prices equals the objective probability distribution given by the economic model. Arguing that otherwise profit opportunities could be exploited, the author supposes that scarce information is incorporated into rational expectations and, hence, public predictions based on the same information will not affect individual expectations.

The Muthian notion of rationality was further formalized in the contributions by Lucas (1972, 1973, 1976) and Sargent (1973). Specifically, under the hypothesis of rational expectations it is assumed that economic agents know the true model of the economy, know the probability distributions and rules of motion for all exogenous variables and are computationally able to combine this information to produce optimal forecasts (Sargent, 1973, p. 439). This allows the replacement of agents' subjective expectations with the mathematical expectations operator:

$$p_t^e = E_t(p_{t+1}|I_t(z)) \tag{1.1}$$

Agents' expectations of next period's price p_{t+1} formed in period t are thus equal to the objective mathematical expectations E_t, conditional on the public information set $I_t(z)$, which is itself a function of exogenous processes in z. Note that information in $I_t(z)$ contains all information of previous periods, so that $I_t \supseteq I_{t-1}$. Furthermore, rational expectations are unbiased and efficient, implying that expectation errors $p_{t+1} - E_t(p_{t+1}|I_t(z))$ depend solely on exogenous stochastic disturbances and are orthogonal to public information in $I_t(z)$, see Lucas (1972).[1] Rational expectations as formalized in equation (1.1) have become a powerful tool for the analysis of modern macroeconomic models, which solve for systems of linear difference equations with forward-looking agents using methods of dynamic programming, see for instance Blanchard and Kahn (1980).

Much of the literature following the 'rational expectations revolution' by Lucas and Sargent and the 'natural rate debate' initiated by Phelps (1967) and Friedman (1968), states that with rational expectations, monetary policy will be ineffective in stabilizing real quantities in the long run and, with fully flexible prices, even in the short run (Sargent, 1996).

However, due to widespread empirical evidence of real effects of monetary policy at least in the short run, recent macroeconomic models retain a role for monetary policy in stabilizing the real economy, see Woodford (2003). This is achieved by introducing

[1]See also Maag (2010a) for a survey on the emergence of rational expectations and tests for rationality.

nominal rigidities[2] into the model, namely staggered prices (and wages) as in Taylor (1980) or Calvo (1983). Under Calvo (1983) pricing, firms underly a fixed, exogenous probability θ that they will not be able to set a new optimal price in any given period, where θ is not influenced by the time evolved since the last price adjustment. Firm i's price $p_{t,i}$ set in period t is thus a geometrically weighted average of current and future optimal prices p^*, since the firm does not know when it will be able to set prices again:

$$p_{t,i} = \theta \sum_{j=0}^{\infty} (1-\theta)^j E_t(p^*_{t+j}) \tag{1.2}$$

Aggregate prices p_t are then a weighted average of past prices set by firms:

$$p_t = \theta \sum_{j=0}^{\infty} (1-\theta)^j p_{t-j,i} \tag{1.3}$$

The New Keynesian DSGE model, building on rational expectations, but including nominal rigidities, has become the new workhorse of modern macroeconomics, see Clarida et al. (1999) for a survey.

1.2 Deviations from Muthian Rationality

Although rational expectations in the Muth (1961) sense have been very successful in macroeconomic models due to their conceptual and mathematical beauty, the concept has been criticized for imposing unrealistically high levels of knowledge and computational ability on economic agents. Thereby, models with rational forward-looking agents predict that aggregate prices and output follow white noise processes around their steady state equilibrium, thus neglecting the high persistence empirically observed in aggregate data (Rudd and Whelan, 2005). Similarly, shocks to monetary policy in the model have maximum impact on output and inflation in the period of the shock, whereas empirical analysis states a prolonged effect of shocks with a hump-shaped impulse response.[3]

[2]Some models also include real rigidities, such as habit formation in consumption, capital adjustment costs, variable capital utilization or employment adjustment costs, see Gail (2004) for a survey.

[3]Evidence of inertia in U.S. inflation is presented by Fuhrer and Moore (1995) as well as Gordon (1997). Christiano et al. (2005) and Rotemberg and Woodford (1997) estimates VAR models with U.S. data and find a hump-shaped impulse-response function of both aggregate output and inflation after a monetary policy shock.

Empirical analysis of professionals' and households' inflation expectations and perceptions also frequently rejects rationality criteria.[4] Analyzing survey data for the UK, Benford and Driver (2008) find that 50% of respondents form inflation expectations on the basis of their current inflation perceptions. Similarly, Branch (2004, 2007), Pfajfar and Zakelj (2009), Pfajfar and Santoro (2008) and Maag (2010b) provide empirical and experimental evidence of heterogeneity in inflation expectations. The remainder of this section thus briefly presents theories that incorporate rational or behavioral deviations from Muthian rationality, serving as a theoretical basis for the research in this thesis.

1.2.1 Near-Rationality

With the aim of providing a model allowing for real effects of money supply shocks in the short run, Akerlof and Yellen (1985) present a theory of near-rationality. Under the condition that agents' objective function be differentiable in own prices and wages, the authors show that near the optimum, small deviations from full rationality in price or wage setting will only impose second-order losses on profits in terms of the policy shock. Nevertheless, they may cause first-order effects on real variables. Thus, assuming that firms have some monopoly power or that consumers underly imperfect information, Akerlof and Yellen (1985) show that near-rationality can lead to inertial wage and price behavior, causing real effects of monetary policy shocks.

The effects of near-rational wage and price setting on inflation regimes and the Phillips curve tradeoff are further evaluated in Akerlof et al. (1996, 2000). Akerlof et al. (2000) show that in a low inflation regime, near-rational behavior can lead to wage and price setting consistently below the level which would be expected relative to nominal aggregate demand, resulting in a long-run tradeoff between inflation and unemployment. Near-rational wage and price setting may be caused by partial or full money illusion of workers at low inflation rates or by an incomplete incorporation of future price changes into expected inflation. However, once inflation becomes higher than some threshold, losses from not incorporating price changes into wages and prices become sufficiently high, so that agents will increasingly adopt fully rational behavior. Another aspect of workers' near-rationality concerns the typically observed downward rigidity of nominal wages. Akerlof et al. (1996) show that with downward wage rigidity, the natural rate of

[4] Studies that reject rationality of inflation expectations using survey data for the U.S. and European economies include, *inter alia*, Batchelor and Dua (1987), Thomas (1999), Forsells and Kenny (2002), Mankiw et al. (2004), Souleles (2004) and Dias et al. (2010). Jonung and Laidler (1988) as well as Lein and Maag (2011) reject rationality of inflation perceptions for a panel of European countries.

unemployment depends on inflation, thus output and unemployment will be maximized at moderate, but positive rates of inflation.

1.2.2 Sticky Information

Motivated by the observation that the New Keynesian Phillips curve with sticky prices as in Calvo (1983) cannot account for the observed persistence in inflation, Mankiw and Reis (2002) propose an alternative formulation, termed the sticky information Phillips curve. The concept of sticky information employs the assumption that economic agents receive information about macroeconomic conditions slowly, due to the costs related to acquiring and processing new information. Hence, although they are assumed to set new prices each period, pricing may occur on the basis of outdated information. The sticky information model by Mankiw and Reis (2002) thus presents another rational deviation from Muthian full rationality, which is explained by the costs of producing rational forecasts.

Using a mechanism similar to Calvo pricing, the authors assume that agents are subject to a fixed, exogenous probability λ of being able to update to the current information set. Since this probability is assumed to stay constant over time, expectations of agents under sticky information can be aggregated similarly to the Calvo expression in equation (1.2), where the aggregate price p_t is a function of past expectations of the optimal price p_t^*, formed when agents last updated their information set:

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j} p_t^* \tag{1.4}$$

The sticky information model is extended to households' consumption choices and workers' wage setting problem in a DSGE setting in Mankiw and Reis (2001, 2003, 2007). The authors argue that with sticky information, the model can replicate the stylized facts of a hump-shaped impulse response of output and inflation to a monetary policy shock, of the persistence in aggregate variables and resolves the problem of sticky price DSGE models that generate a boom, rather than a recession, in response to an announced and credible disinflation.

Microfoundations for sticky information affecting consumers and producers are given in Reis (2006a,b). The author derives the optimal length of inattentiveness for households and firms and finds that it is adversely affected by the volatility of income shocks and the deviation of profits from their full information equivalence, but increases with the costs of information updating. Furthermore, Reis (2006a,b) shows that second-order costs to information updating lead to first-order effects on the length of inattentiveness. In this respect, consumers and producers under sticky information behave near-rationally as in Akerlof and Yellen (1985). Building on the sticky information model in Ball et al. (2005), Branch et al. (2006, 2009) endogenize the optimal degree of inattentiveness by firms. The authors assume that firms minimize a quadratic loss function relating the price with firm-specific inattentiveness λ to the optimal price given some economy-wide $\overline{\lambda}$, accounting for a fixed cost of information updating. They show that a symmetric Nash equilibrium with endogenous inattentiveness exists as the fixed point of the map describing firms' optimal choices.

1.2.3 Rational Inattention

Similar to the sticky information theory by Mankiw and Reis (2001, 2002, 2003, 2007), the theory of rational inattention by Sims (2003) suggests that the limited information-processing capacity rationally induces economic agents to deviate from full rationality. Borrowing from information theory, the information flow is modelled as the rate of uncertainty-reduction, where uncertainty is measured by the concept of entropy. For a random variable X with probability distribution function (pdf) $p(X)$, its entropy is given by the formula $-E[log(p(X))]$, see Sims (2003). The author assumes that limited information-processing takes the form of a channel, where input of the random variable X generates output in the form of another random variable Z with pdf $q(Z|X)$. Using Bayes' rule, the pdf of X conditional on output Z is then given by:

$$r(X|Z) = \frac{p(X)q(Z|X)}{\int p(x)q(Z|X)dx}, \tag{1.5}$$

and information on X portrayed through output Z can be measured by the change in entropy:

$$E[log_2(r(X|Z))|Z] - E[log_2(p(X))] \tag{1.6}$$

Note that while rational inattention implies costs to the processing of information similar to the assumption in sticky information models, it differs in important aspects. Firstly, new information is assumed to arrive continuously, but can only be partly processed due to limitations on the information channel. Secondly, under rational inattention agents can never attain full rationality in the Muthian sense, while with sticky information agents are fully rational whenever they update their information set.

The effects of rational inattention by firms on optimal monetary policy in a partial or general equilibrium setting are analyzed in the models by Mackowiak and Wiederholt (2009, 2010), Paciello and Wiederholt (2011) as well as Adam (2007, 2009).

1.2.4 Heterogeneous Expectations

A further approach at modeling rational deviations from Muthian rationality can be found in the literature on heterogeneous expectations. Arguing that fully rational expectations may impose too much knowledge and ability on the part of agents, models with rationally heterogeneous expectations show that it may be rational to form expectations on the basis of less advanced predictors. In their seminal paper, Brock and Hommes (1997) introduce the concept of adaptively rational equilibrium as a form of bounded rationality where agents rationally choose between a set of predictors for future prices, based on their past forecast performance. Expected prices for next period p^e_{t+1} formed with predictor j are thus generally defined as:

$$p^e_{t+1} = H_j(\overline{P}_t), \tag{1.7}$$

where $\overline{P}_t = (p_t, p_{t-1}, p_{t-2}, ...)$ is a vector of the current and past prices. In order to discriminate between predictors, Brock and Hommes (1997) then assume that agents evaluate predictor performance by continuously measuring net realized profits Π^j_{t+1} with predictor j:

$$\Pi^j_{t+1} = p_{t+1} S(H_j(\overline{P}_t)) - c(S(H_j(\overline{P}_t))) - C_j, \tag{1.8}$$

where profits are determined by next period's supply S and costs c, which are both functions of the predictor $H_j(\overline{P}_t)$ specifying expected prices. Furthermore, a fixed cost for obtaining forecasts of type j, C_j, is assumed. The performance measure $U_{j,t+1}$ for predictor j is then given as a weighted average of past net profits, where the weights are assumed to sum to one:

$$U_{j,t+1} = \sum_{k=1}^{M} \omega_{j,k} \Pi^j_{t+1-k}, \quad \sum_{k=1}^{M} \omega_{j,k} = 1 \tag{1.9}$$

Using a specification from discrete choice theory as in Manski and McFadden (1981), the fraction $n_{j,t+1}$ of agents rationally choosing predictor j in the next period is then defined as the multinomial logit map from relative predictor fitness to the probability of agents choosing predictor j:[5]

$$n_{j,t+1} = \frac{\exp(\gamma U_{j,t+1})}{\sum_{l=1}^{K} \exp(\gamma U_{l,t+1})}, \tag{1.10}$$

where K is the number of alternative predictors and the parameter γ measures the so-called 'intensity of choice', describing the degree to which agents switch predictors following changes in $U_{j,t+1}$.[6]

The discrete choice model by Brock and Hommes (1997) in equations (1.9) and (1.10) is applied to survey data on U.S. inflation expectations in Branch (2004, 2007) who finds evidence of agents' switching between naive, adaptive, as well as VAR forecasts and expectations with sticky information. Branch and Evans (2006, 2007, 2011) employ the switching mechanism in equation (1.10) to explain predictor choice in a theoretical model where agents are restricted to choose between different underparameterized models to obtain forecasts, similarly to the learning models in Evans and Honkapohja (2001, 2003). Brazier et al. (2008) and Brock and de Fontnouvelle (2000) incorporate heterogeneous inflation expectations into OLG models and De Grauwe (2008) analyzes switching between simple heuristics regarding output and inflation expectations in a DSGE model without rational expectations.

1.2.5 Behavioral Approaches

Finally, a vast literature dealing with psychologically determined deviations from full rationality has emerged in behavioral economics. Here, we will focus on two approaches, namely Prospect Theory by Kahneman and Tversky (1979) as well as Tversky and Kahneman (1981, 1991) and the availability hypothesis by Tversky and Kahneman (1973).

Developed as a behavioral alternative to expected utility theory by von Neumann and Morgenstern (1944), Kahneman and Tversky present Prospect Theory as a theory of decisions under risk, where choices between prospects or gains are influenced by certain psychological phenomena. A central argument of Prospect Theory concerns the evaluation of outcomes with respect to a reference point and the concept of loss aversion. Regarding the perception of price changes and expectations of future prices, this implies that economic agents evaluate perceived or expected prices relative to a reference price,

[5] The multinomial logit map can be derived under the assumption of an infinite population, sampling with replacement and an underlying logistic distribution, see Cosslett (1981).

[6] Note that the limiting case of $\gamma = +\infty$ yields the neoclassical deterministic model, where $n_{j,t+1}$ becomes a point mass at the optimal predictor, see Brock and Hommes (1997).

which can be interpreted as the ‘normal’ or ‘fair’ price (Thaler, 1985 and Rotemberg, 2005, 2008). Prices above the reference price will then be coded as ‘losses’, while prices below the reference price are perceived as ‘gains’. Due to loss aversion, price changes in the loss region will be perceived more strongly than those in the gain region. This leads to an asymmetric value function with a kink at the reference price and a steeper slope in the loss region. Loss aversion with respect to inflation perceptions and expectations is analyzed both experimentally and empirically in Jungermann et al. (2007) and Capistrán and Timmermann (2009).

Another behavioral bias potentially affecting inflation perceptions and expectations is the availability hypothesis in Tversky and Kahneman (1973), who report experimental evidence that agents assess the frequency of events by the ease with which they can be remembered. With respect to the perception and expectation of current or future price changes, this may cause agents to allocate a relatively larger weight to price changes of frequently bought goods. Empirical support for this effect is given, for instance, in Jungermann et al. (2007) and Kurri (2006). Since frequently bought goods often have relatively smaller absolute prices, the availability bias may be exacerbated by the effect of the Weber-Fechner Psychophysical Law, whereby perceived inflation is a logarithmic function of actual price changes (Thaler, 1980 and Batchelor, 1986). Indeed, Tversky and Kahneman (1981) present experimental evidence that economic agents perceive a price change of 5% to be higher if the base price is small, rather than high.

1.3 Objectives and Outline of the Thesis

The theories discussed in the section above all concern deviations from full rationality in the Muthian sense. Models of near-rationality, sticky information, rational inattention and rationally heterogeneous expectations in sections 1.2.1–1.2.4 describe the expectation formation process as a rational choice between forecast accuracy and costs to the formation of more sophisticated forecasts, which may result in agents rationally choosing non-rational predictors. By contrast, the behavioral theories presented in section 1.2.5 describe psychologically inherent biases to the formation of perceptions and expectations.

This thesis contributes to the analysis of the formation process of households’ inflation perceptions and expectations, exploring the heterogeneity of expectations and the interrelations between perceived and expected inflation. Specifically, in chapters 2 and 3 a DSGE model with endogenous sticky information is proposed, extending the model by Mankiw and Reis (2001, 2002, 2003, 2007). Incorporating the switching mechanism from the heterogeneous expectations literature in Brock and Hommes (1997), the probability of obtaining new information is modeled as an endogenous and time-varying choice between rational or sticky information expectations, where the former are subject to a ‘rationality cost’. Since agents are assumed to base their decision on the mean squared forecast errors of their predictor, the model also includes aspects of rational inattention as in Sims (2003), where it is assumed that aggregate information arrives continuously, but is only partly processed. An empirical motivation for this approach is given by Branch (2007) who claims that a sticky information model with dynamic inattentiveness fits the distribution of households’ inflation expectations in the U.S. from the University of Michigan Surveys of Consumers best.

Applying the switching mechanism of Brock and Hommes (1997) to both output and inflation expectations after the model solution is found, numerical simulations of the DSGE model suggest that agents choose predictors in line with near-rationality as in Akerlof and Yellen (1985) and Akerlof et al. (2000): The degree of attentiveness towards output and inflation, λ_t^y and λ_t^π, is positively correlated with the variance of the forecasted variable. Hence, high variability raises the costs of inattentiveness, inducing agents to pay closer attention to recent information. The share of agents with rational inflation expectations is additionally positively correlated with the variance of interest rates, providing a link from monetary policy to inflation expectations. Furthermore, on average agents are found to be more rational with respect to output than with respect to inflation. This is due to the fact that agents know the model and are thus aware that monetary policy targets inflation with a higher coefficient compared to the output gap, so that they can ‘delegate’ rationality to the central bank.

Important results from earlier sticky information models, such as the hump-shaped impulse response of inflation to a monetary policy shock, are reproduced in the model with endogenous inattentiveness in chapter 2. However, the high persistence of aggregate variables can only be reproduced when the shocks are assumed to be autocorrelated. Regarding the role of monetary policy, adherence to the Taylor principle is found to be a necessary and sufficient condition for determinacy. Nevertheless, a higher coefficient on inflation in the Taylor rule increases output variability, while a larger coefficient on the output can stabilize output without significantly affecting inflation.

The model in chapter 2 is extended in chapter 3 by allowing for feedback from agents’ predictor choice to the model solution. The model is thus solved recursively, where agents’ degree of inattentiveness, λ_t, affects the model solution in $t + 1$, when agents decide on λ_{t+1}, affecting the solution on $t+2$ and so forth. While all main results from chapter 2 remain robust, the model with recursive inattentiveness in chapter 3 generates considerable persistence in aggregate output and inflation without assuming autocorrelated demand or cost-push shocks. Analysis of long-run stability shows that across a range of shocks and Taylor rule coefficients, all endogenous variables converge to their steady state after an initial shock with shares of rational agents close to zero. Chaotic long-run dynamics as in the Cobweb model by Brock and Hommes (1997) are thus ruled out. Furthermore, with recursive inattentiveness, the Taylor principle is a necessary, but no longer a sufficient condition for determinacy. Rather, in order to avoid multiple equilibria, monetary policy should also target the output gap with a small coefficient.

While there exists a large literature rejecting Muthian rationality of households' inflation expectations and perceptions from survey data, alternative models of the formation process of inflation perceptions and the interrelation between perceived and expected inflation have only been partly analyzed.[7] Hence, in the empirical part of the thesis, survey data of households' inflation perceptions and expectations from the European Commission's Joint Harmonized EU Program of Business and Consumer Surveys is evaluated.

Chapter 4 analyzes the formation of inflation perceptions using qualitative survey data for a panel of 10 European economies for the sample period 1996–2008. Specifically, it is hypothesized that the concepts of loss aversion from Prospect Theory by Kahneman and Tversky (1979) and Tversky and Kahneman (1981, 1991) as well as the availability hypothesis by Tversky and Kahneman (1973) may affect the perception of inflation, causing a deviation of perceived from actual inflation. In particular, the assumption of loss aversion implies that inflation rates above a 'normal' rate of inflation are perceived more strongly than those below, while the availability bias suggests that price changes of frequently bought goods are perceived more strongly than those of less frequently bought categories. Inspired by the work of Brachinger (2006, 2008) who presents an index of perceived inflation based on the assumptions of loss aversion and availability, empirical tests are constructed to assess whether these hypotheses are verified by the data. Evaluating both the pre-Euro and post-Euro periods, results suggest evidence of loss aversion and the availiability bias before the Euro introduction. However, after the Euro cash changeover the reference rate of inflation seems to have increased and

[7] Brachinger (2006, 2008) proposes an alternative index of perceived inflation based on the assumptions of loss aversion and the availability bias, where some evidence of the availability bias is also presented in Lein and Maag (2011). The influence of socioeconomic factors on the formation of inflation perceptions is discussed in Del Giovane et al. (2008) and Jonung and Conflitti (2008). Evidence of feedback between perceived and expected inflation is shown for instance in Jonung (1981) and van der Klaauw et al. (2008), however, the direction of causality remains unclear.

a generally increased awareness of price changes in both frequently and less frequently bought goods categories is observed.

With full rationality, inflation expectations should be formed on the basis of actual inflation. However, Benford and Driver (2008) and Maag (2010b) provide evidence that households form expectations based on perceived, rather than actual, inflation. Furthermore, Traut-Mattausch et al. (2004) experimentally show that past inflation expectations may influence current perceptions of price changes. Chapter 5 thus analyzes the interrelation between perceived and expected inflation in detail, using quantitative survey data from the Swedish Consumer Tendency Survey. Comparing results for a low-inflation period from 1998–2007 to an extended sample including high and volatile inflation in 2008, dynamic feedback effects and Granger causality between perceptions and expectations are evaluated. In line with the agenda-setting literature by McCombs (2004) and the importance of the media's coding of information stressed in Sims (2003) and Carroll (2001, 2003), the effect of media articles on the formation and interrelation of perceived and expected inflation is analyzed throughout the chapter. While inflation expectations seem to be affected symmetrically by news on inflation, results for the extended sample suggest that inflation perceptions are influenced asymmetrically only by negative news regarding inflation. Thus, media reports may induce a bias in perceptions which could be due to loss aversion as in chapter 4. Regarding the interrelation between actual, perceived and expected inflation, results for the low-inflation sample imply Granger-causality from expectations to perceptions. In a structural vector error correction (SVEC) framework, shocks to perceptions have persistent effects on expectations, while the reverse effect is less pronounced and the media has only small effects. By contrast, once high inflation in 2008 is accounted for, interaction between inflation perceptions and expectations increases and media effects become more important.

Chapter 2

Why don't people pay attention? Endogenous Sticky Information in a DSGE Model*

*This chapter is based on Dräger (2010).

2.1 Introduction

The observation that standard New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models with sticky prices are not able to reproduce the inertia and delayed responses to shocks observed in empirical inflation and output data, led to the derivation of the sticky information model by Mankiw and Reis (2001, 2002, 2003, 2007). In the model, it is assumed that costs related to acquiring and processing information cause a fraction of agents to form expectations using outdated information sets, resulting in so-called sticky information. Thus, only agents obtaining the current information are able to form rational expectations, while those who do not update receive information gradually as news spread through the economy. This type of costless and effortless information acquisition can be thought of as obtained by observing other agents' behavior or by chance, for example through the media, as in the epidemiology model of Carroll (2001, 2003).[1]

Sticky information models in Mankiw and Reis (2001, 2002, 2003, 2007) take the probability of updating to the most recent information set, λ, as an exogenous parameter. Hence, each period all agents face the same probability of updating their information set and this probability stays constant over time. Building on their approach, we analyze a sticky information DSGE model with heterogeneous expectations and an endogenous and time-varying share of agents with rational expectations, λ_t: Agents of type 1 have rational expectations with respect to output and inflation, while agents of type 2 are subject to sticky information and thus form expectations using an outdated information set. Since new information is costly due to processing costs, in our model agents face a trade-off between the accuracy of their forecasts and a fixed 'rationality cost' for obtaining the most up-to-date information. Introducing a switching mechanism derived in a seminal paper by Brock and Hommes (1997), agents switch to being rational once the losses from sticky information become too high. Conversely, if the cost outweighs the gains from rational forecasts, agents choose not to pay for new information and use the outdated information set from the date when they last paid the rationality cost. Thereby, the share of agents that update information each period, λ_t, becomes endogenous and time-varying.[2]

[1] Empirical estimates of the share of agents updating information each period are given for the U.S. in Carroll (2003) and for a European sample in Döpke et al. (2008a,b)

[2] Analyzing survey data of households' inflation expectations in the U.S., Branch (2004, 2007) finds evidence of rationally heterogeneous inflation expectations with switching as in Brock and Hommes (1997). Specifically, in Branch (2007) the author reports evidence of expectation formation consistent with sticky information, where the model fits the data best when the degree of inattentiveness is allowed

To our knowledge, so far Branch et al. (2006, 2009) present the only attempt to fully endogenize the degree of inattentiveness in a sticky information model. Building on the model in Ball et al. (2005), the authors assume that firms choose their degree of inattentiveness by minimizing a quadratic loss function comparing the firm-specific price given a firm-specific λ to the optimal price given some fixed economy-wide probability of updating information $\overline{\lambda}$. The authors furthermore introduce a fixed cost to information processing that is defined relative to λ^2. It is then shown that a symmetric Nash equilibrium with endogenous inattentiveness exists as a fixed point of the map giving firms' optimal degree of inattention. Our model differs from their insightful approach in that we allow agents to evaluate the fitness of their predictor continuously, so that each period the share of rational agents is determined as a form of recursive learning, given the evolution of the model economy over time. Furthermore, our model incorporates sticky information for both households and firms and we analyze endogenous inattentiveness with respect to both output and inflation, respectively.

Simulating our model, we find considerable time-variation in λ_t once the rationality cost exceeds a certain level. Agents seem to be more rational with respect to output than to inflation, which could be due to the higher coefficient on inflation in the Taylor rule, causing households to confer rationality upon the central bank. Furthermore, the share of rational expectations is positively correlated with the variance of the variable to be forecasted: Agents are willing to pay the cost for up-to-date information if changes in the variable are relatively large and remain inattentive otherwise. Thus, households opt for forecasts without fully rational information if the losses from doing so are relatively small. This is a central result of models with near-rationality of agents by, e.g., Akerlof and Yellen (1985) and Akerlof et al. (1996, 2000). In addition, we find that the share of rational inflation expectations rises with an increase in the variance of the nominal interest rate: Agents choose to pay more attention to inflation when monetary policy becomes more active. This result is also in line with near-rationality and emphasizes the strong link between monetary policy and inflation expectations.

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to vary over time. Further empirical evidence of pervasive heterogeneity in inflation expectations and switching between models of expectation formation is given by Pfajfar and Zakelj (2009) and Pfajfar and Santoro (2008), who find evidence that agents form either rational, sticky or static expectations (analyzing the distribution of the Michigan survey of households for the US) and that they switch models frequently in an experimental setting. In a similar vein, Maag (2010b) evaluates heterogeneity in quantitative households' expectations data from the Swedish Consumer Tendency Survey. Estimating a Gaussian mixture model of underlying distribution densities, the author finds that a large share of households form static expectations based on their perception of actual inflation, while smaller shares form rational, adaptive and static expectations based on official inflation rates, respectively.

With regard to monetary policy, important results of sticky information models in Mankiw and Reis (2002, 2007) are reproduced by our model with endogenous and time-varying λ_t: We also find a hump-shaped response of inflation to a monetary policy shock and that determinacy depends only on the reaction coefficient to inflation in the Taylor rule, as pointed out by Meyer-Gohde (2009). Analysis of second moments and impulse-response functions shows, however, that optimal monetary policy aiming at stabilizing the economy should not put too much weight on inflation (as long as the Taylor principle is fulfilled). A relatively large weight on the output gap minimizes fluctuations of output in response to monetary policy and cost-push shocks, while inflation is only marginally affected. However, this comes at the risk of overreacting to a positive demand shock, which then produces a small recession in output as monetary policy is tightened overly strictly.

The chapter is structured as follows: Section 2.2 presents a short overview of the related literature on sticky information and models with rational inattention, section 2.3 derives the model, while section 2.4 presents simulation results and policy analysis. Finally, section 2.5 concludes.

2.2 Literature Review

While most DSGE models assume sticky prices with Calvo (1983) pricing, Mankiw and Reis (2001, 2002, 2003, 2007) apply the Calvo mechanism to the arrival of new information, so that agents underly an exogenous probability each period that they will not be able to update their information set. Thereby, although the rational expectations hypothesis is retained, agents are restricted in the sense that new information is distributed slowly throughout the economy. As a result, macroeconomic relations are governed by an infinite sum of geometrically weighted lagged expectations, resulting in hump-shaped impulse-responses of inflation and output to shocks and a significantly higher degree of inertia in the variables.[3] Microfoundations for the sticky information model are derived by Reis (2006a,b), where both consumers and firms rationally choose to only sporadically update their information due to the costs related to acquiring and processing information. However, and although Reis derives the optimal length of inat-

[3]Several studies have compared models with sticky prices and sticky information. While Trabandt (2007) claims that the hybrid New Keynesian model with sticky prices and habit formation can outperform the sticky information model, Dupor et al. (2010) find evidence for both sticky prices and sticky information in aggregate US data.

tentiveness for both firms and consumers, in the aggregate the probability of updating is given exogenously for all agents.

Branch et al. (2006, 2009) present the first approach to endogenize the degree of inattentiveness of firms by solving for the fixed point of a map defining the optimal choice of λ from a loss function describing expected profit losses and a fixed cost. The authors find that positive feed-back from a price-stabilizing monetary policy may exist if the policy allows firms to pay less attention to aggregate shocks, resulting in higher overall persistence. At relatively low information costs, monetary policy may thus be able to lower price and output variability simultaneously if price stability is not targeted too vigorously. Introducing adaptive learning of both policymakers and firms, Branch et al. (2006) additionally find that after an exogenous increase in the degree of price stabilization policy, in the short run price stability increases, while output becomes more volatile. As λ adapts to its lower equilibrium, however, the variability of both prices and output falls.

While to our knowledge this is the first theoretical approach modelling heterogeneous expectations as a choice between rational or sticky information in a DSGE setting, there exists a wide literature on rationally heterogeneous expectations. Motivated by the observation that full rationality in the Muth (1961) sense will impose too much knowledge and ability on agents, models with heterogeneous expectations assume that agents may rationally choose less accurate predictors. In their seminal paper, Brock and Hommes (1997) introduce a cobweb model where agents rationally choose between rational versus naive forecasts, based on forecast performance relative to the costs of predictors. Branch (2004, 2007) presents the first empirical test of the Brock and Hommes (1997) model and finds evidence of rational heterogeneity in inflation expectations from the University of Michigan Surveys of Consumers in the U.S. Especially the latter contribution serves as an empirical motivation for our model with endogenous and time-varying inattentiveness: Branch (2007) presents maximum-likelihood estimates of a discrete choice model as in Brock and Hommes (1997) with sticky information, allowing for time-varying choices between updating frequencies of 1, 3, 6 and 9 months. The author finds that the static sticky information model by Mankiw and Reis (2001, 2002, 2003, 2007) is rejected and the dynamic sticky information model with time-varying choices between updating frequencies fits the data best.[4] The largest share of agents seems to update either every 3 or every 6 months. Nevertheless, Branch (2007) reports that in some periods, the static sticky information model also captures the characteristics of the sur-

[4]Dynamic rationally heterogeneous expectations model with predictor choices between naive, adaptive and VAR forecasts also capture dynamics in the Michigan survey well, see Branch (2004, 2007).

vey distribution well, especially in periods of low volatility in inflation, implying little switching between updating frequencies.[5]

Related to the models of sticky information and building on the seminal work by Sims (2003), Mackowiak and Wiederholt (2009, 2010), Paciello and Wiederholt (2011) as well as Adam (2007, 2009) present models with rational inattention. Since firms have limited capacity for processing information, it is assumed that only a fraction of the available information can be incorporated into pricing decisions. In a DSGE setting, Mackowiak and Wiederholt (2009, 2010) find that firms adjust prices every period, but react imperfectly to shocks. However, an increase in the variance of aggregate variables may cause firms to allocate more attention towards these shocks.

Studying optimal monetary policy, Paciello and Wiederholt (2011) find that complete price stabilization is optimal under rational inattention even if shocks cause inefficient fluctuations under perfect information. Adam (2007, 2009) shows that monetary policy may have strong real effects if prices are strategic complements and shocks have little persistence. Overall, strong discretionary stabilization policies may exacerbate volatility in the economy, because they lead to larger information processing errors of firms and, thus, higher volatility of prices and output. Similarly, Woodford (2005) also evaluates optimal monetary policy in the case of near-rational private sector expectations, defined as unspecified deviations from the central bank's expectations. He finds that commitment and history-dependence of optimal policy become even more important with uncertainty about agents' expectations than when assuming rational expectations.

2.3 The Model

2.3.1 Heterogeneous Expectations

We derive a standard DSGE model with heterogeneity in agents' expectations. Hence, the mathematical expectations operator E is replaced with $\widetilde{E}$, which is a convex combination of the expectation formation rules in the economy. Specifically, we assume there exist two types of forecasts:

[5] Further approaches employing the switching mechanism by Brock and Hommes (1997) are Branch and Evans (2006, 2007, 2011) who model predictor choice when agents are restricted to choose between different underparameterized models to obtain forecasts in the spirit of learning models as in Evans and Honkapohja (2001, 2003). Similarly, Brazier et al. (2008) and Brock and de Fontnouvelle (2000) present OLG models with heterogeneous inflation expectations, where the latter analyze the model properties as the number of predictors converges towards infinity. Finally, De Grauwe (2008) models switching between simple heuristics regarding output and inflation expectations in a DSGE model without rational expectations.

1. Agent 1 has rational expectations: $E_t^{RE} = E_t$

2. Agent 2 is subject to sticky information: $E_t^{SI} = \overline{\lambda} \sum_{j=0}^{\infty} (1 - \overline{\lambda})^j E_{t-1-j}$,

Agents of type 2 deviate from rational expectations in the sense that they know the relevant model and are computationally able to compute rational forecasts, but rationally choose to forecast with outdated information. This is due to the costs related to processing new information, which provides the motivation for sticky information in, e.g., Ball et al. (2005), Reis (2006b) and Branch et al. (2009). As long as agents decide not to pay these costs, they will belong to the second group and use information from the date when they last updated their information set. The expectations operator for agents with sticky information, E_t^{SI}, is hence a weighted aggregate of all agents that use information sets older than the current one. The weighting parameter $\overline{\lambda}$ can be interpreted as the average share of agents with rational expectations and is assumed to be constant over time.

Note, however, that we assume that all agents are able to evaluate the accuracy of their forecasts and thus receive some aggregate information continuously. In that sense, our model deviates from the definition of sticky information in Mankiw and Reis (2001, 2002, 2003, 2007) and is closer to models of rational inattention as in Sims (2003), where information arrives continuously, but is only partly processed.[6] We make this assumption because agents use their forecast accuracy as a metric for the loss they incur when not paying for the most recent information, as shown in section 2.3.5.[7]

Once an agent decides to pay the costs for processing the newest information (what we term the 'rationality cost'), he or she becomes an agent of type 1 and forecasts with rational expectations. Agents stay in group 1 as long as they pay the rationality cost each period. If they decide not to update their information set in a certain period, they will continue to forecast with their information from last period, and thus become subject to sticky information again. For as long as they choose not to update, they will remain in group 2 and forecast with increasingly outdated information. Hence, agents

[6]See also the models with rational inattention à la Sims (2003) in Mackowiak and Wiederholt (2009, 2010) , Paciello and Wiederholt (2011) and Adam (2007, 2009).

[7]Although we model agents' choice between predictors in a highly stylized manner, there exists empirical evidence that people seek information that confirms their beliefs and that they tend to ignore contradictory information as long as resulting errors are not too harmful, see for instance Mullainathan and Shleifer (2005). Thus, agents may keep their 'prior beliefs' even when new information arises. As shown in Gentzkow and Shapiro (2008), this may also influence the way new information is portrayed in the media. Hence, it seems reasonable to assume that agents may forecast with outdated information even though they are aware of their current forecast error.

that switch from being rational to forecasting under sticky information do not loose information, but rather neglect new information that arrives as time progresses.

In line with the literature on heterogeneous expectations, the aggregate expectations index is then defined as a convex combination of agents with rational and sticky information:

$$\widetilde{E}_t(x) \equiv \lambda_t E_t^{RE}(x) + (1-\lambda_t)E_t^{SI}(x) = \lambda_t E_t(x) + (1-\lambda_t)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}(x), \quad (2.1)$$

where λ_t is the endogenous share of rational agents in period t, the time-varying analogue to the probability that agents may update their information set, which was given exogenously in the sticky information model.

In order to facilitate the derivation of aggregate expressions for output and inflation with heterogeneous expectations, we follow Branch and McGough (2009) and make the following assumptions: Regardless of whether agents have rational or sticky information, it is assumed that they correctly perceive known quantities and steady state values. Also, mathematical rules regarding linear expectations operators are assumed to hold. Most importantly, a necessary condition for aggregation is the assumption that the law of iterated expectations hold not only within, but also across heterogeneous expectations operators. We thus assume that agent's expectations of other agents' expectations regarding future variables equal their own expectations of that future variable, thereby imposing a certain structure on higher-order beliefs.[8] Finally, it is assumed that all agents have the same expectations regarding expected differences in limiting wealth and, as in standard sticky information models, in the limit all agents have rational expectations.

2.3.2 Households' Problem

The model follows a standard New Keynesian set-up, see for instance Walsh (2003) and Mankiw and Reis (2007), but includes heterogeneous expectations E_t^j: The model economy is populated by a large number of infinitely-lived households, that differ only with respect to the expectations operator used, but otherwise have identical preferences

[8] Note that our assumptions for aggregation of heterogeneous expectations are similiar to those necessary in Reis (2006b) for the derivation of the sticky information Phillips curve from inattentive firms. For an analysis of optimal monetary policy in models with imperfect information processing accounting for higher-order beliefs, see Adam (2007, 2009).

and endowments. Households of type j maximize utility using the expectations operator E_t^j, where we assume constant relative risk aversion:

$$\max \quad U(C_t, N_t) = E_t^j \sum_{k=0}^{\infty} \beta^k \left[\frac{C_{t+k}^{1-\sigma} - 1}{1-\sigma} - \frac{N_{t+k}^{1+\eta}}{1+\eta} \right] \tag{2.2}$$

subject to the budget constraint

$$C_t + \frac{B_t}{P_t} = \frac{W_t}{P_t} N_t + (1 + i_{t-1}) \frac{B_{t-1}}{P_t} + \Pi_t, \tag{2.3}$$

(abstracting from money, capital and the government), where households finance current consumption C_t and real bond holdings $\frac{B_t}{P_t}$ from real wage income of their work efforts, $\frac{W_t}{P_t} N_t$, interest payments from last period's real bond holdings, $(1+i_{t-1})\frac{B_{t-1}}{P_t}$ and profits transferred from firms, Π_t. The composite consumption good, C_t and the aggregate price index P_t are defined as Dixit-Stiglitz aggregators of individual consumption goods $c_{t,i}$ produced by firm i and their respective prices:

$$C_t = \left(\int_0^1 c_{t,i}^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}} \tag{2.4}$$

$$P_t = \left(\int_0^1 p_{t,i}^{1-\theta} di \right)^{\frac{1}{1-\theta}} \tag{2.5}$$

From the first-order conditions we get the log-linearized Euler equation:

$$\hat{c}_{t,j} = E_t^j \hat{c}_{t+1,j} - \frac{1}{\sigma} (\hat{i}_t - E_t^j \pi_{t+1}), \tag{2.6}$$

where variables with a hat denote deviations from steady state. We thus get the standard log-linearized Euler equation for each agent j, where individual deviations of consumption from its steady state differ according to the expectations operator employed. Note that the specification of the Euler equation in (2.6) implicitly assumes that all agents can observe deviations of the current nominal interest rate from its steady state in $\hat{i}_t$. This assumption can be interpreted as representing the willingness of all agents to pay for the costs related to processing information on changes in the interest rate set by the central bank.

Aggregation of the Euler equation in (2.6) across households makes use of the assumptions in Branch and McGough (2009) given in the previous section, especially the assumption that the law of iterated expectations holds across heterogeneous expectations and that agents have identical expectations in the limit. A detailed derivation of the aggregate Euler equation is given in the mathematical appendix in chapter A. Iterating forward and aggregating across agents gives, after some algebra:

$$\hat{c}_t = \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}), \tag{2.7}$$

where $\widetilde{E}_t(x) = \lambda_t E_t(x) + (1-\lambda_t)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}(x)$. To arrive at the New Keynesian IS-relation, recall that without investment, government and net exports $\hat{y}_t = \hat{c}_t + u_t$,[9] where we define u_t as an i.i.d. demand shock, capturing exogenous changes in aggregate demand components other than consumption. We thus get for the New Keynesian IS curve with heterogeneous expectations:

$$\hat{y}_t = \widetilde{E}_t\hat{y}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}) + u_t, \tag{2.8}$$

which gives, when spelling out heterogeneous expectations included in $\widetilde{E}_t$:

$$\begin{aligned} \hat{y}_t &= \lambda_t\left(E_t\hat{y}_{t+1} + \frac{1}{\sigma}E_t\pi_{t+1}\right) + (1-\lambda_t)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}\left(\hat{y}_{t+1} + \frac{1}{\sigma}\pi_{t+1}\right) \\ &- \frac{1}{\sigma}\hat{i}_t + u_t \end{aligned} \tag{2.9}$$

As in the standard sticky information model, we thus find that the IS-relation contains an infinite sum of past expectations on steady-state output and inflation, reflecting the fact that a fraction of agents uses outdated information sets for forecasting. However, here the fractions of households in each group are determined endogenously by the switching mechanism given below.

2.3.3 Firms' Problem

Next, we model firms' behavior. Again, we assume a large number of firms that produce individual consumption goods, which together form the composite consumption basket. We also assume that firms are owned by households and are thus subject to the same heterogeneity in expectations faced by households.[10]

In line with the standard New Keynesian model, we assume a Cobb-Douglas production function with constant returns to scale:

[9]Problems and implications of this approach are discussed in Groessl (2008).

[10]This is in contrast to Mankiw and Reis (2007) who assume that households and firms are subject to different probabilities of updating their information set.

$$y_{t,i} = Z_t N_{t,i}, \tag{2.10}$$

where Z_t denotes technology (equal for all firms) and $N_{t,i}$ is the amount of labour used by firm i to produce $y_{t,i}$. Since we assume market clearing, we can set $Y_t = C_t$, ignoring government consumption and net exports. Finally, from the cost minimization problem of households, we have for the demand of goods produced by firm i:

$$y_{t,i} = \left(\frac{p_{t,i}}{P_t}\right)^{-\theta} C_t \tag{2.11}$$

Again, we will assume that the assumptions from Branch and McGough (2009) hold. In line with the framework applied in the sticky information models, we assume that firms set optimal prices each period, hence the only rigidity in the model applies to the stickiness of information. Firms maximize expected profits subject to the production function in (2.10) and the demand function in (2.11):

$$\max_{p_{t,i}} E_t^i \left[\frac{p_{t,i} y_{t,i}}{P_t} - \frac{W_t N_{t,i}}{P_t}\right] \tag{2.12}$$

s.t.

$$y_{t,i} = Z_t N_{t,i} \Rightarrow N_{t,i} = y_{t,i} Z_t^{-1} \tag{2.13}$$

$$y_{t,i} = \left(\frac{p_{t,i}}{P_t}\right)^{-\theta} C_t \tag{2.14}$$

Inserting the constraints and log-linearizing gives for the deviation of the optimal price set by firm i from its steady state:

$$\hat{p}^*_{t,i} = E_t^i \left[\hat{p}_t + \hat{\varphi}_t\right] \tag{2.15}$$

where $\hat{\varphi}_t$ is the deviation from steady state of real marginal costs defined as $\varphi_t \equiv (W_t/P_t)Z_t^{-1}$. In order to express the optimal price in terms of the output gap rather than real marginal costs, we follow Ball et al. (2005) and derive an expression for natural output under flexible prices as a function of technology shocks. After some algebra, this gives for the aggregate price index, where the detailed derivation is shown in the mathematical appendix in chapter A:

$$
\begin{aligned}
\hat{p}_t &= \lambda_t E_t^{RE}\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] + (1-\lambda_t)E_t^{SI}\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] \\
&= \widetilde{E}_t\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] \qquad (2.16)
\end{aligned}
$$

where $\psi = \frac{\sigma+\eta}{1+\eta\theta}$, $\hat{y}^n$ is the natural output under flexible prices and full information and e_t is an i.i.d. cost-push shock resulting, for instance, from unexpected wage or tax changes. Aggregate prices are thus determined by the fraction of agents correctly perceiving current prices and the output gap, and by those using outdated information to form expectations on current variables.

Finally, in order to derive an expression for aggregate inflation, we lag equation (2.16) by one period and subtract it from (2.16). To facilitate the derivations, we suppress the time-index of the time-varying share of rational agents, setting $\lambda_t \approx \overline{\lambda}$. This essentially rules out an effect of large changes in the share of rational agents between two periods on inflation, assuming that about 50% use the rational and the sticky information predictor, respectively. After some algebra, this gives the sticky information Phillips curve, where detailed derivations are in the mathematical appendix in chapter A:

$$
\begin{aligned}
\pi_t &= \frac{\psi\overline{\lambda}}{1-\overline{\lambda}}(\hat{y}_t - \hat{y}_t^n) + \frac{\overline{\lambda}}{1-\overline{\lambda}}e_t \\
&+ \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}\left[\pi_t + \psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right] \qquad (2.17)
\end{aligned}
$$

Time-variation in heterogeneous expectations is then re-introduced by allowing agents to choose between expectation operators in period *t-1*:

$$
\begin{aligned}
\pi_t &= \frac{\psi\overline{\lambda}}{1-\overline{\lambda}}(\hat{y}_t - \hat{y}_t^n) + \frac{\overline{\lambda}}{1-\overline{\lambda}}e_t + \lambda_{t-1}E_{t-1}\left[\pi_t + \psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right] \\
&+ (1-\lambda_{t-1})\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-2-j}\left[\pi_t + \psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right] \qquad (2.18)
\end{aligned}
$$

As before, when inserting heterogeneous expectation formation, we see that due to the fraction of agents under sticky information, an infinite sum of past expectations features also in the Phillips curve with flexible prices.

2.3.4 Monetary Policy Rule

As usual in the New Keynesian DSGE framework, our model is closed by defining a monetary policy rule. In line with the sticky information DSGE model in Mankiw and Reis (2007), we assume a Taylor rule with interest rate smoothing, targeting actual values of inflation and the output gap:

$$\hat{i}_t = \mu_i \hat{i}_{t-1} + (1-\mu_i)\left(\mu_\pi \pi_t + \mu_{y^{gap}}(\hat{y}_t - \hat{y}_t^n)\right) + \eta_t, \tag{2.19}$$

where η_t is an i.i.d. shock to monetary policy. Note that we assume the central bank to perfectly perceive current values of inflation and the output gap, while at the same time accounting for the heterogeneity in agents' expectations implicitly contained in realized values of inflation and the output gap.

2.3.5 Time-Varying Inattentiveness

After deriving the model expressions governing output, prices and nominal interest rates, we endogenize the degree of inattentiveness by allowing a choice between the losses incurred when forecasting with outdated information and the costs for processing the newest information set.

Agents are confronted with a choice problem of the following kind: On the one hand, they face a positive cost of processing information necessary for forming rational forecasts, which we define as 'rationality cost'. On the other hand, they have the prospect of gaining in consumption and profits if the rational forecast produces a more accurate solution to the utility and profit maximization problems than forecasts under sticky information. The reverse argument applies to choices regarding sticky information, where we assume that there is no cost of obtaining and processing past information. Agents' choice problem thus relates to the literature on rational inattention founded by Sims (2003), who analyzes rational deviations from full information due to limited information processing capacities. However, in contrast to Sims (2003) we assume that it is possible for agents to attain rationality once they are willing to pay the cost for it.

Deriving microfoundations for the sticky information model, Reis (2006a,b) computes the optimal length of inattentiveness for households and firms and finds that it falls with the volatility of income shocks and the difference between profits under full or limited information, but increases with the costs of updating consumption and production plans. Furthermore, the author shows that second-order rationality costs lead to first-order effects on the degree of inattentiveness. This is because deviations from full information near the optimum only cause second-order losses in profits or consumption, so that agents are willing to incur those losses when faced with a rationality cost.[11] Although the microfoundations in Reis (2006a,b) thus already incorporate the choice problem introduced here, in the aggregate a stationary equilibrium of inattentiveness is assumed, where all agents face the same exogenous probability of updating their information set each period.

In line with the literature on heterogeneous expectations, we define agents' mean squared forecast errors as the metric for their losses from forecasting under sticky information. Similarly, Branch et al. (2009) endogenize the degree of inattentiveness of firms by proposing a loss function measuring expected profit losses as the squared difference of a firm's individual price from the optimal price, given some economy-wide degree of inattentiveness $\overline{\lambda}$.[12] Building on the model with sticky information of firms in Ball et al. (2005), the authors then show that this loss function is monotonically decreasing in agents' own degree of inattentiveness λ. Finally, the optimal degree of inattentiveness is determined via a function minimizing the choice between the loss and a fixed cost of information processing defined relative to λ^2.

While our measure of the losses from agents' inattentiveness is similar to the one in Branch et al. (2009), our approach differs in one important aspect: The former solve for the equilibrium share of predictors given the entire history of the model economy, whereas we assume that agents continuously evaluate their past forecast performance and recursively solve for the optimal degree of inattentiveness each period. In that sense, agents are assumed to engage in a form of recursive learning and the degree of inattentiveness may vary over time as shocks arrive to the economy.[13] We thus

[11] In that sense, agents behave near-rationally as in Akerlof and Yellen (1985). The authors define near-rationality as "non-maximizing behavior in which the gains from maximizing rather than nonmaximizing are small in a well-defined sense" (Akerlof and Yellen, 1985, pp. 823–824), meaning that losses from near-rationality are only second-order in terms of the deviation from the long-run equilibrium, but may nevertheless cause first-order changes in real activity.

[12] Brock and Hommes (1997) show that using mean squared forecast errors or realized net profits as the measure of predictor fitness yields similar results.

[13] While we model time-varying inattentiveness as the choice between current or outdated information, i.e. rational or sticky information expectations, Branch (2007) estimates the fraction of agents updating with frequencies 1, 3, 6 or 9 months. De Grauwe (2010) and Brazier et al. (2008) also allow agents to switch between predictors over time, using the framework of Brock and Hommes (1997).

assume that although agents may choose not to pay the costs for incorporating new information into their forecasts, they nevertheless receive some information on their forecast accuracy. It can be argued that this type of behavior is consistent with the microfoundations in Reis (2006b), where the optimal degree of inattentiveness is found to be a function of the volatility of shocks as well as the difference between profits under full or sticky information.

We thus derive an expression of predictors' relative net benefit, defined as mean squared forecast errors under rational or sticky information, where the former are forced to pay a positive rationality cost:

$$U_t^{RE} = -\sum_{k=0}^{\infty} \left[\omega_k(\hat{x}_{t-k} - E_{t-k-1}\hat{x}_{t-k})^2 + K^{RE}\right] \tag{2.20}$$

$$U_t^{SI} = -\sum_{k=0}^{\infty} \left[\omega_k(\hat{x}_{t-k} - \overline{\lambda} \sum_{j=k-1}^{\infty} (1-\overline{\lambda})^j E_{t-j-1}\hat{x}_{t-k})^2\right], \tag{2.21}$$

where equation (2.20) gives forecast performance of rational expectations and (2.21) that of expectations under sticky information, respectively. Each period, agents evaluate the forecast performance of their current expectations operator against the realizations of the forecasted variable in that period, which recursively adds up to the sum of all forecast errors. Note that only rational agents face the positive rationality cost K^{RE} of obtaining up-to-date information, which has to be paid each period. The weights ω_k are assumed to be geometrically declining and sum to one, defined as $\omega_k = (1-\rho)\rho^k$, with $0 < \rho < 1$ measuring the degree of agents' memory of past mean squared forecast errors.

Solving backwards we get, after some algebra, for the forecast performance of rational expectations:[14]

$$U_t^{RE} = \rho U_{t-1}^{RE} - (1-\rho)\left[(\hat{x}_t - E_{t-1}\hat{x}_t)^2 + K^{RE}\right] \tag{2.22}$$

Similarly, we get for expectations under sticky information:

$$U_t^{SI} = \rho U_{t-1}^{SI} - (1-\rho)(\hat{x}_t - \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-j-2}\hat{x}_t)^2 \tag{2.23}$$

It can thus be seen that this period's forecast performance of a particular process for expectation formation is a weighted average of its squared forecast error this period and last period's forecast performance, incorporating mean squared forecast errors of

[14]For a detailed derivation, see the mathematical appendix in chapter A.

previous periods. As ρ approaches zero in the limit, agents' memory becomes shorter and the forecast performance is solely based on this period's squared forecast error. Conversely, as ρ converges towards one, agents put more weight on the forecast performance of previous periods and tend to ignore the most recent squared forecast error. Note that the specification of forecast accuracy in equations (2.22) and (2.23) implies that agents inherit knowledge of previous mean squared forecast errors of the specific predictor when switching from rational to sticky information or *vice versa*.

Finally, following the seminal paper by Brock and Hommes (1997), we assume a multinomial logit map from agents' predictor accuracy to their degree of inattentiveness.[15] The multinomial logit form to model agents' probability of making a specific choice from a set of alternatives is frequently used in discrete choice theory, see Manski and McFadden (1981). Under the assumption of an infinite population, sampling with replacement and an underlying logistic distribution, the probability of choosing i conditional on a set of exogenous variables z and parameters θ can be modelled as follows (Cosslett, 1981):

$$P(i|z,\theta) = \frac{\exp(V_i(z,\theta))}{\sum_{j=1}^{M}\exp(V_j(z,\theta))}, \tag{2.24}$$

where M denotes the number of alternatives and $V_i(z,\theta)$ gives a general measure of the desirability of alternative i, which can be interpreted as the average utility of alternative i. We thus model the proportion of rational agents as a function of the relative net benefit from being rational compared to forecasting with sticky information. The probability that agents choose to be rational, i.e. the share of rational agents, is then given each period by the following expression:

$$\lambda_t = \frac{\exp(\gamma U_t^{RE})}{\exp(\gamma U_t^{RE}) + \exp(\gamma U_t^{SI})}. \tag{2.25}$$

Consequently, the probability that agents forecast with sticky information equals:

$$(1-\lambda_t) = \frac{\exp(\gamma U_t^{SI})}{\exp(\gamma U_t^{RE}) + \exp(\gamma U_t^{SI})}, \tag{2.26}$$

where the parameter γ measures the so-called 'intensity of choice', that is the degree to which agents let their choice of an expectations rule be influenced by its relative net benefit. A higher intensity of choice will lead agents to switch predictors more quickly

[15] This approach is also employed in Branch and Evans (2006, 2007, 2011), who analyze models where agents are forced to choose between different underparameterized predictors. As in Branch et al. (2009), the authors solve for the equilibrium share of agents for each predictor.

as soon as the forecasting performance of a particular predictor improves relative to the other. As pointed out by Brock and Hommes (1997), the limiting case of $\gamma = +\infty$ yields the neoclassical deterministic model, where agents form a point mass at the optimal predictor.

Since in our model agents form expectations both on future inflation and future output (i.e. the output gap), we define two separate switching mechanisms, where agents evaluate the accuracy of the inflation and output forecasts under rational and sticky information, respectively. Although both inflation and output are affected by the same shocks driving the economy, we argue that it nevertheless makes sense to analyze the formation of inflation and output expectations separately. Doing so allows us to account for the different weights attached to each shock in the dynamic processes for inflation and output. More importantly, it provides a way to analyze the effect of different weights on inflation and output in the monetary policy rule on agents' decision for a predictor on inflation and output. The expression $\hat{x}_t$ in equations (2.22) and (2.23) is thus replaced with $\hat{y}_t$ and π_t, respectively. This gives for the time-varying shares of agents with rational output and inflation expectations:

$$\lambda_t^y = \frac{exp(\gamma U_{y,t}^{RE})}{exp(\gamma U_{y,t}^{RE}) + exp(\gamma U_{y,t}^{SI})}. \tag{2.27}$$

$$\lambda_t^\pi = \frac{exp(\gamma U_{\pi,t}^{RE})}{exp(\gamma U_{\pi,t}^{RE}) + exp(\gamma U_{\pi,t}^{SI})}. \tag{2.28}$$

Distinguishing between heterogeneous expectations regarding output and inflation, we then obtain for the IS curve and the Phillips curve:

$$\begin{aligned} \hat{y}_t &= \lambda_t^y E_t \hat{y}_{t+1} + \frac{1}{\sigma}\lambda_t^\pi E_t \pi_{t+1} + (1-\lambda_t^y)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}\left(\hat{y}_{t+1}\right) \\ &+ \frac{1}{\sigma}(1-\lambda_t^\pi)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}\left(\pi_{t+1}\right) - \frac{1}{\sigma}\hat{i}_t + u_t \end{aligned} \tag{2.29}$$

$$\begin{aligned}\pi_t &= \frac{\psi\overline{\lambda}}{1-\overline{\lambda}}(\hat{y}_t - \hat{y}_t^n) + \frac{\overline{\lambda}}{1-\overline{\lambda}}e_t \\ &+ \lambda_{t-1}^y \psi E_{t-1}\left(\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right) + \lambda_{t-1}^\pi E_{t-1}\pi_t \\ &+ (1-\lambda_{t-1}^\pi)\overline{\lambda}\sum_{j=0}^{\infty}\left(1-\overline{\lambda}\right)^j E_{t-2-j}\pi_t \\ &+ (1-\lambda_{t-1}^y)\overline{\lambda}\sum_{j=0}^{\infty}\left(1-\overline{\lambda}\right)^j E_{t-2-j}\left(\psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right)\end{aligned} \tag{2.30}$$

2.3.6 Solving for the Equilibrium

Solving for the equilibrium dynamics of the model with endogenous and time-varying sticky information poses two difficulties: First, as noted in Brock and Hommes (1997), the feedback from agents' switching between predictors to the model parameters can lead to complicated dynamic equilibrium dynamics if the intensity of choice, γ, is sufficiently high. Second, the presence of an infinite sum of past expectations in combination with forward-looking expectations in the model equation implies that the state-space of the model has an infinite dimension. This makes it intractable for standard DSGE solution algorithms, see Mankiw and Reis (2007).

We avoid the problem of feedback from agents' switching decisions to the model dynamics by imposing that the switching mechanism only operates after the model solution is found and dynamic paths for the variables have been simulated. By doing so, we are able to analyze how agents would optimally choose predictors over time, taking as given the evolution of prices, output and interest rates. The timing of events is thus as follows: First, the sticky information model with fixed shares of rational agents is solved and simulated, given an exogenous path of shocks. Then, we simulate how agents would hypothetically choose optimal predictors during each period of the simulated model economy. In the following chapter 3, we allow for feedback from agents' switching of predictors to the parameters model economy and analyze issues of equilibrium dynamics in more detail.

A solution to the sticky information model is found numerically with the algorithm from Meyer-Gohde (2010), which accounts for the infinite sum of lagged expectations by calculating matrices of limiting coefficients as the sum approaches minus infinity. The algorithm then solves for the undetermined coefficients of the MA(∞) representation with a Generalized Schur Decomposition, using the limiting coefficients as an approximation for the infinite horizon of lagged expectations. Simulations are carried out over 1500 periods, where the first 500 periods are used to initialize the model and generate lagged expectations and are then dropped.

Calibrated parameters are taken from McCallum (2001) for the baseline model and shown in Table A.1 in the appendix in chapter A. The parameters η and θ are not included in McCallum (2001)'s model, we set values to obtain a value for the elasticity of inflation with respect to the output gap similar to the one estimated by Mankiw and Reis (2007). In order to keep the model as parsimonious as possible, we do not include any lagged endogenous variables and assume no autocorrelation in the shocks. Exceptions are the assumption of interest rate smoothing by the central bank, and the technology shock on natural output $\hat{y}_t^n$, which is assumed to be autocorrelated of order 1. Furthermore and in line with De Grauwe (2010), we set the standard deviation of the demand and cost-push shocks in the IS and Phillips curve equal to each other.[16]

The switching parameter γ in equations (2.27) and (2.28) is set to 10000 as in Brock and Hommes (1997) and agents' degree of memory of past forecast errors ρ in equations (2.22) and (2.23) is taken to be 0.5 as in De Grauwe (2010).[17] We set initial values of λ_t for both inflation and output expectations to 0.5. The rationality cost is defined relative to the mean squared forecast error of expectations under sticky information. Simulating the model over 1000 periods, assuming no costs of rationality and no persistence in forecast errors, we obtain mean values of $U_{y,t}^{SI}$ and $U_{\pi,t}^{SI}$. Parameters of K_y^{RE} and K_π^{RE} then range from 0% to 100% of the mean forecast error under sticky information, see Table (A.2) in the appendix in chapter A. We take the value of $K_{y/\pi,t}^{RE} = 50\%$ of $U_{y/\pi,t}^{SI}$ as the baseline cost.

[16]Of course there exist numerous calibration approaches to DSGE models such as ours. As a robustness check, we compared impulse-response functions and simulated series for the share of rational agents from our baseline model to models with parameters from Mankiw and Reis (2007) and De Grauwe (2010). Allowing for autocorrelation of the shocks as in Mankiw and Reis (2007) or for lagged endogenous variables as in De Grauwe (2010) considerably increases the persistence of the simulated series and the impulse-responses. Otherwise, our results remain robust. The simulations with alternative calibrations are available from the author upon request.

[17]We checked for robustness of our results with values of γ and ρ ranging between $0 \leq \gamma \leq 15000$ and $0 \leq \rho \leq 1$. As expected, switching becomes more frequent, the higher the value of γ and the lower the value of ρ, respectively. Nevertheless, overall our results remain robust also for high and low values of both γ and ρ. Results are available from the author upon request.

2.4 Results

2.4.1 Simulation Results and Impulse-Response Functions

Second moments and first-order serial correlation coefficients of inflation, output and nominal interest rate series, simulated with the McCallum (2001) calibration and a baseline rationality cost of 50% of mean squared forecast errors under sticky information, are presented in Table 2.1. All values were obtained by simulating the model 1000 times over 1000 periods.

Table 2.1: Descriptive Statistics of Simulated Variables

Variable	Standard Deviation	AR(1) coefficient
π_t	0.0298	-0.0496
$\hat{y}_t$	0.0312	0.1525
$\hat{i}_t$	0.0121	0.6482

Note: Values are obtained from simulating the model 1000 times over 1000 periods.

Results in Table 2.1 imply that the persistence of the simulated series for output and inflation cannot match the high degree of autocorrelation found in empirical data. In the case of inflation, the model even suggests a negative correlation coefficient. This problem often encountered in standard DSGE models is due to the fact that no autocorrelation in the shocks, except for the technology shock, was assumed in contrast to the sticky information DSGE of Mankiw and Reis (2007) and, apart from the coefficient of interest rate smoothing, no lagged endogenous variables were included as in the DSGE with heterogeneous expectations in De Grauwe (2010). Hence, sticky information by itself seems not to be able to produce the inertia necessary to reproduce empirical properties of inflation and output data.

Figures 2.1–2.4 show impulse-response functions of inflation, output and the nominal interest rate to a one-standard-deviation demand shock in the IS curve, a cost-push shock in the Phillips curve, a monetary policy shock and a technology shock. As expected, the interest rate increases after a positive demand shock and then returns slowly to its steady state. Inflation also increases after a demand shock and undershoots before returning to its steady state value, which is due to the fact that firms target prices and not inflation. A positive cost-push shock causes interest rates to rise while simultaneously dampening

Figure 2.1: Impulse Responses to a Demand Shock

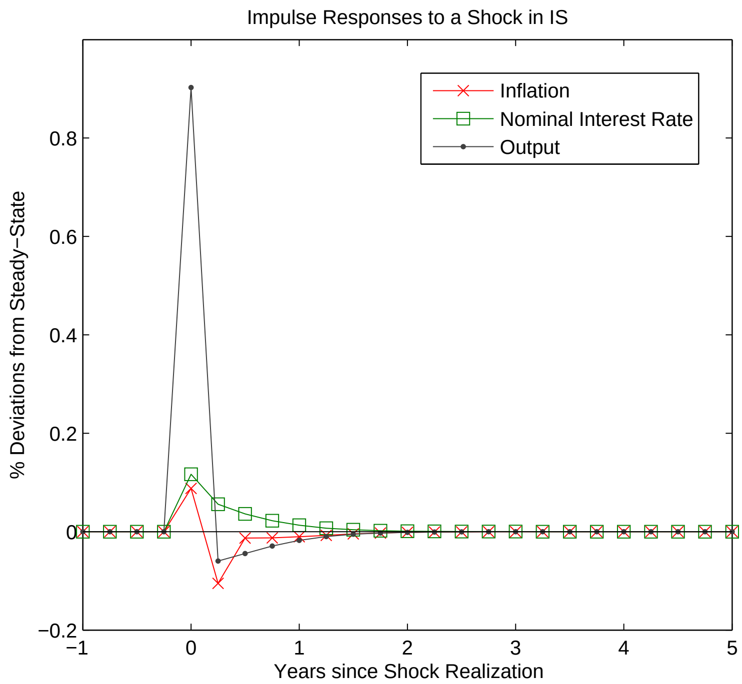


Figure 2.2: Impulse Responses to a Cost-Push Shock

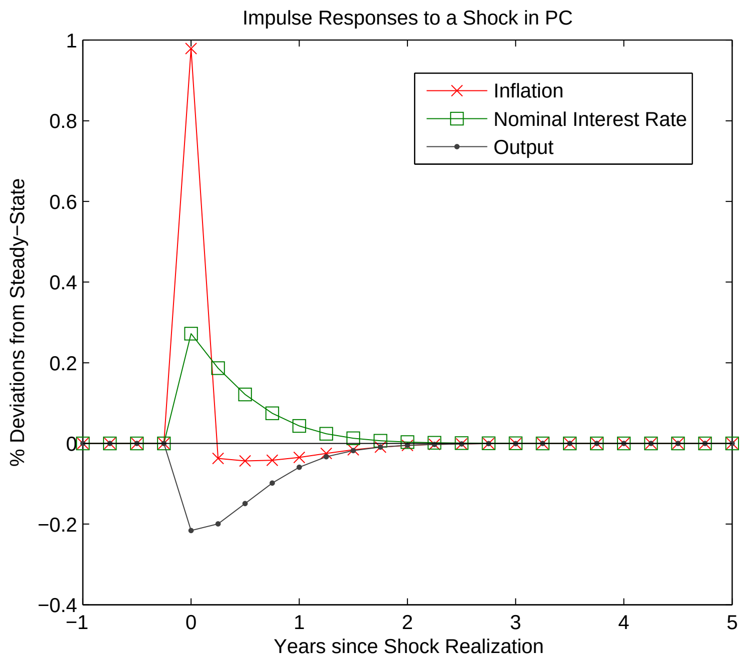


Figure 2.3: Impulse Responses to a Monetary Policy Shock

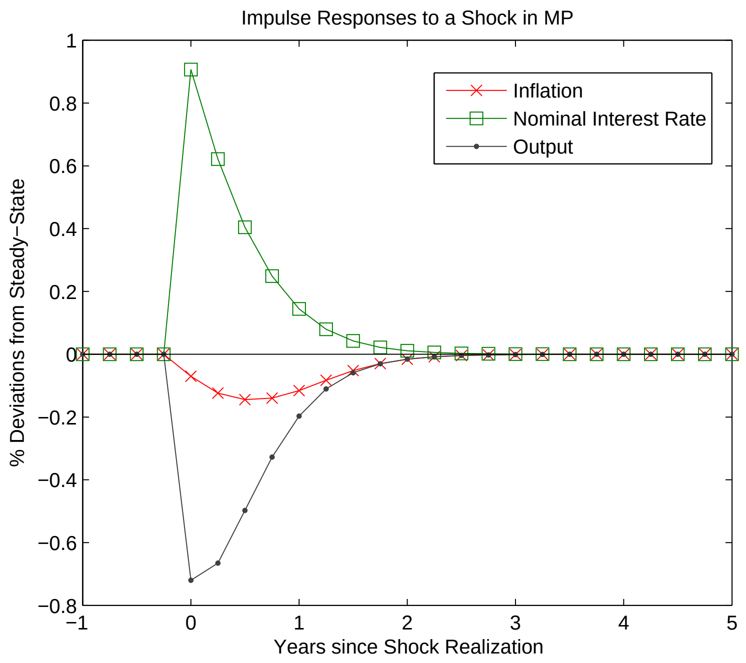
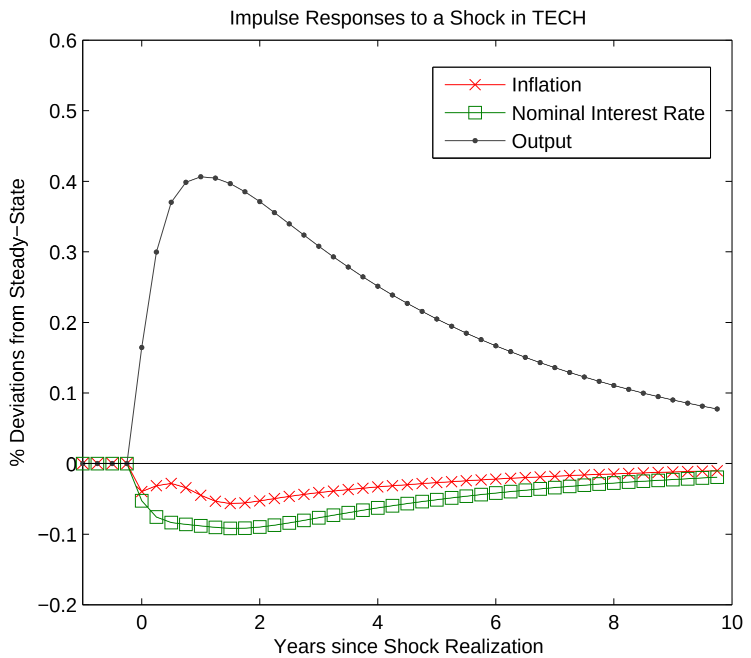


Figure 2.4: Impulse Responses to a Technology Shock



output, leading to a persistent recession and negative deviations of inflation from its steady state from the second quarter after the shock onwards.

The impulse-response functions of a one-standard-deviation rise in the interest rate shown in Figure 2.3 show the typical hump-shaped response of inflation obtained from sticky information Phillips curves, e.g. in Mankiw and Reis (2002, 2006, 2007): A positive shock to the nominal interest rate has a gradually dampening effect on inflation, which continues to hold until two years after the shock, when all series have returned to their steady states. Hence, one important feature of the sticky information models is retained also with heterogeneous expectations and endogenous inattentiveness. The impulse-response function of output to a monetary shock also shows considerable persistence, albeit without a hump-shaped pattern. This is due to the fact that our IS curve deviates from the one derived in Mankiw and Reis (2007) in that it includes past expectations of future, instead of present, inflation and output.

Finally, a positive technology shock has a pronounced boosting effect on output, which is due to the autocorrelation assumed in the shock. Both inflation and the interest rate are reduced in response to the shock, leading to the long-lasting boom in output.

2.4.2 Time-Varying Inattentiveness

Rational Expectations with Varying Rationality Costs

After evaluating the dynamics of the simulated variables in the model, we turn to analyzing the dynamics of the time-varying shares of rational inflation and output expectations. From Table 2.2 we see that the shares of agents with rational output expectations, λ_t^y, and with rational inflation expectations, λ_t^π, only fluctuate between zero and one if the rationality cost is at least 25% of the mean squared forecast error under sticky information. Even then, on average as much as 80% and 73%, respectively, of all agents have rational output and inflation expectations. As the rationality cost increases to 50% of the mean squared forecast error and higher, on average the share of rational agents approaches zero. Nevertheless, even if new information is costless, so that on average close to every agent will be rational, there may occur shocks such that between one third and one half of the population chooses to ignore the new information, at least for short periods of time.

With regard to the standard deviation of the shares of rational agents, for both output and inflation expectations variability is highest at medium costs of 50%. This implies that at this cost, agents have no predetermined preference for either rational expectations or those under sticky information, but rather switch to their preferred

Table 2.2: Time-Varying Inattentiveness

Variables		Min.	Max.	Mean	Std.	Av. Cycle Length
λ_t^y	K=0%	0.6667	1	0.9935	0.0414	9.403
	K=10%	0.2152	1	0.9578	0.1216	7.241
	K=25%	0.0052	1	0.8085	0.3232	5.782
	K=50%	0.0000	1	0.4842	0.4651	2.974
	K=75%	0.0000	1	0.2506	0.4223	4.690
	K=100%	0.0000	1	0.1229	0.3119	10.789
λ_t^π	K=0%	0.5084	1	0.9931	0.0390	8.709
	K=10%	0.1008	1	0.9421	0.1414	8.438
	K=25%	0.0011	1	0.7283	0.4159	5.260
	K=50%	0.0000	1	0.3439	0.4607	4.132
	K=75%	0.0000	1	0.1339	0.3250	8.046
	K=100%	0.0000	1	0.0486	0.2038	21.390

Note: The mean is obtained from simulating the model 1000 times over 1000 periods. The average switching frequency is calculated in quarters.

expectations operator depending on current shocks to the economy. At lower costs, the advantages of rational expectations generally outweigh the costs. Conversely, at higher costs the gains in utility and profits from rational forecasts can generally not make up for the high costs of new information.

Interestingly, whereas the variability between rational and sticky expectations is approximately equal for output and inflation expectations, on average agents seem to be more rational with respect to output than to inflation: At costs of 50% of the mean squared forecast error, on average 50% of agents choose to forecast with rational expectations regarding output, but only 34% form rational inflation expectations.[18] The difference is highest at medium costs and decreases with costs falling to 0% or rising to 100%. It thus seems that agents are more concerned about obtaining new information on changes in output than on inflation. This could be explained by the relatively larger weight of inflation compared to the output gap in the central bank's Taylor rule.[19]

[18]Note that our mean value of λ_t^π fits well with the estimate of about 0.3 found in Carroll (2003) for the U.S. and in Döpke et al. (2008a,b) for a panel of European countries.

[19]Our finding is robust also with a high weight on the output gap relative to inflation in the Taylor rule: As monetary policy puts a larger weight on the output gap, mean values of λ_t^y and λ_t^π converge, and *vice versa*. Nevertheless, in order to guarantee determinacy, the central bank has to react more

Hence, if monetary policy convincingly targets inflation, agents feel that they can afford to delegate rationality to the central bank by paying less attention to current shocks on inflation.[20]

Furthermore, we analyze the average cycle length of λ_t^y and λ_t^π, that is the average number of periods in which agents use their forecasting rule before switching to an alternative rule. We define cylces of rationality and non-rationality, respectively, where simulated values of λ_t belong to the same cycle if they deviate from the previous period's value by not more than a tolerance parameter of 0.001. For both λ_t^y and λ_t^π swichting is most frequent at a medium cost of 50%, where on average agents switch rules for output forecasting every three quarters and for inflation forecasting every four quarters. Generally, the switching frequency increases as the rationality cost rises from 0 to 50%, and then decreases again as it further rises to 100%. Especially at very high costs of 100% of the mean squared forecast error agents seem very reluctant to switch forecasting rules and keep rules for an average of 11 and 21 quarters, respectively. Comparing the shares of agents with rational output and inflation expectations, our model suggests that for rationality costs of 50% and higher there is considerably more switching of forecasting rules for output than for inflation, while at lower costs switching frequencies are relatively similar. Again, this indicates a possible link between inflation targeting by the central bank and the rationality of inflation expectations: At a noticeable cost for rational expectations, agents feel a stronger need to adjust output expectations and switch inflation forecasting rules less frequently, since they know via the Taylor rule that the central bank will pay more attention to stabilizing inflation than output.

Rational Expectations and the Volatility of Inflation and Output

After analyzing time-varying inattentiveness with increasing rationality costs, it remains to evaluate which macroeconomic conditions foster rational expectations. There exists a large literature on the question of disagreement among forecasters and its relation to the level and the volatility of inflation and output. To mention just a few, Mankiw et al. (2004) analyze disagreement in inflation expectations for the US and find that the sticky

than one-to-one to changes in inflation, which might be enough for agents to concentrate more on information regarding recent developments in output.

[20]For example, Bryan and Palmqvist (2005) analyze survey data of households' inflation expectations for Sweden and the US, and report that the introduction of the Swedish inflation target of 2% significantly increased the proportion of Swedish households who ignore inflation in the recent period of low inflation rates. Conversely, even though inflation was very similar in the US, this effect is not evident in American households' inflation expectations, suggesting an important role of central bank communication for the formation of inflation expectations.

Table 2.3: Time-Varying Inattentiveness and Macroeconomic Variables

Correlation with	λ_t^y	λ_t^π
level π_t	-0.0302	-0.0499
variance π_t	0.0369	0.3958
level y_t	0.0805	0.0245
variance y_t	0.3339	-0.1015
level i_t	-0.1012	-0.0332
variance i_t	0.0477	0.2512

Simulated with $K^{RE} = 50\%$.

information model is well suited to explain the degree of heterogeneity in forecasts. Similarly, Carroll (2001, 2003) proposes microfoundations for the sticky information model in an 'epidemiology model' for inflation expectations, where agents obtain news on inflation via the media. The speed of arrival of news relates to both the level and the volatility of inflation, since we can assume a higher media coverage on inflation in times of high inflation rates or shocks to inflation. While Carroll tests his model empirically for households' inflation expectations in the US, Maag and Lamla (2009) investigate data for Germany and find supportive evidence of Carroll's model. Capistrán and Timmermann (2009) also find that heterogeneity in inflation expectations differs systematically with both the level and the variance of inflation. With respect to firms' expectations regarding the future business outlook, Lamla et al. (2007) provide evidence that firms react strongly to aggregate news shocks, where the impact of the shock differs across sectors.

For the baseline model with a rationality cost of 50% of the mean squared forecast error under sticky information, we analyze the relation between the time-varying degree of inattentiveness and the time-varying variance in the variable to be forecasted. The time-varying volatility of inflation or output is defined as a five-month moving-average of their variance.

Table 2.3 summarizes correlation coefficients of λ_t^y and λ_t^π with respect to the level and variance of inflation, output and nominal interest rates. We find that the share of agents with rational expectations is positively correlated with the variance of the variable forecasted, while correlations with the level of the forecasted variable are low. This suggests that agents choose to be more attentive with respect to inflation and output, as volatility, and hence uncertainty, with respect to the variable increases. Conversely, if inflation and output are relatively stable, agents can afford to ignore new information, since losses from forecasting with outdated information will be low.

The share of rational output expectations λ_t^y does not seem to be significantly correlated with any macroeconomic variable other than the variance in output. Conversely, the share of rational inflation expectations λ_t^π is also correlated with the monetary policy stance: In addition to the variance of the inflation rate, the variance of the nominal interest rate seems to play an important role, suggesting that more agents choose to pay the cost for rational inflation expectations as monetary policy becomes more active.

Our results provide a link between models of near-rationality by, Akerlof and Yellen (1985) and Akerlof et al. (2000), and models of sticky information: With near-rationality, it is assumed that agents will ignore a fraction of inflation as they set wages (and prices) as long as inflation remains below a certain treshold, resulting in a long-run trade-off between inflation and output because losses from doing so are small. Note that a similar result obtains also with regard to firms' optimal length of inattentiveness in Reis (2006b). In our model, agents decide to pay more attention as the variance of the variable forecasted increases and remain inattentive otherwise. Our model thus obtains near-rational behavior of agents in a macroeconomic context, with forecasts under sticky information as the explicit alternative to rational expectations.

2.4.3 The Role of Monetary Policy

In this section, we analyze monetary policy under endogenous sticky information. Specifically, determinacy and optimal monetary policy are evaluated across a range of reaction coefficients μ_π and $\mu_{y^{gap}}$. Note that as we exclude feed-back from agents' switching between predictors to the model solution, all results are obtained with fixed $\lambda^{y,\pi}$.

Since in the limit all agents are assumed to have rational expectations, the well-known eigenvalue accounting method developed by Blanchard and Kahn (1980) can be used to evaluate determinacy also in our model with heterogeneous expectations. We solve the model with six endogenous variables numerically, using the baseline calibration given above for Taylor-rule coefficients on inflation and the output gap ranging between zero and two:[21] $0 \leq \mu_\pi \leq 2$ and $0 \leq \mu_{y^{gap}} \leq 2$.

In contrast to standard determinacy results for DSGE models (Woodford, 2003), we find that stability of our model depends only on μ_π: As long as the Taylor principle is

[21] The upper-bound value of two for μ_π and $\mu_{y^{gap}}$ is chosen somewhat ad hoc. It seems to be a reasonable boundary, however, as it gives equal weights to the regions below and above the Taylor principle of $\mu_\pi \geq 1$. Furthermore, our results are robust to extending the upper bound to higher values.

fulfilled and the central bank reacts more than one-to-one to an increase in the inflation rate, the model will have a unique and stable solution. We thus find no long-run trade-off between inflation and the output gap. This result has been confirmed analytically by Meyer-Gohde (2009) for a DSGE model with a sticky information Phillips curve and is due to the assumption that in the infinite horizon, the model converges to the perfect foresight model with a vertical long-run Phillips curve. As a result, the Taylor principle becomes a necessary and sufficient condition for determinacy. Only at $\mu_\pi \equiv 1$, stability of the model is established by the coefficient on the output gap $\mu_{y^{gap}}$, however, no clear pattern emerges. By contrast, Branch and McGough (2009) find for a DSGE with heterogeneous expectations that the share of non-rational expectations influences stability, either positively if non-rational expectations are adaptive, or negatively if non-rational expectations are extrapolative.

Next, we analyze optimal monetary policy for all values of μ_π and $\mu_{y^{gap}}$ that lead to a stable equilibrium, i.e. $1 < \mu_\pi \leq 2$ and $0 \leq \mu_{y^{gap}} \leq 2$.[22] Since monetary policy reacts to changes in inflation and the output gap in the Taylor rule, we take the stabilization of inflation and output as the objective of monetary policy. Figure 2.5 shows standard deviations of inflation, output and the interest rate across values of μ_π and $\mu_{y^{gap}}$, where we simulated the model 1000 times over 1000 periods to gain robust results.

Regarding the central bank's attentiveness towards inflation, the well-known short-run trade-off between inflation and output emerges:[23] Increasing the reaction coefficient to inflation in the Taylor rule, μ_π, will stabilize inflation at the cost of increasing variability in output. However, in absolute terms our model suggests that the increase in the standard deviation of output is almost five times the decrease in the standard deviation of inflation. Also, variability in nominal interest rates increases with rising μ_π as monetary policy needs to react more forcefully to changes in inflation.

With respect to the central bank's reaction coefficient to the output gap, $\mu_{y^{gap}}$, a different picture emerges: Varying the coefficient between $0 \leq \mu_{y^{gap}} \leq 2$ seems to have no clear effect on the variability of inflation. By contrast, output is stabilized considerably if the central bank reacts strongly to changes in the output gap. Interestingly, variability of the nominal interest rate is minimized at a value of $\mu_{y^{gap}} = 0.5$, which is the value assumed in the McCallum (2001) baseline calibration.

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[22] While one Taylor rule coefficient was varied, the other was set equal to its baseline calibration value.

[23] In a DSGE model with a sticky-information Phillips curve, the exact size of the short-run trade-off in period 0 is $\pi_0 = \frac{\psi\lambda_0}{1-\lambda_0}(\hat{y}_0 - \hat{y}_0^n)$, see Meyer-Gohde (2009).

Figure 2.5: Optimal Policy across Taylor-Rule Coefficients

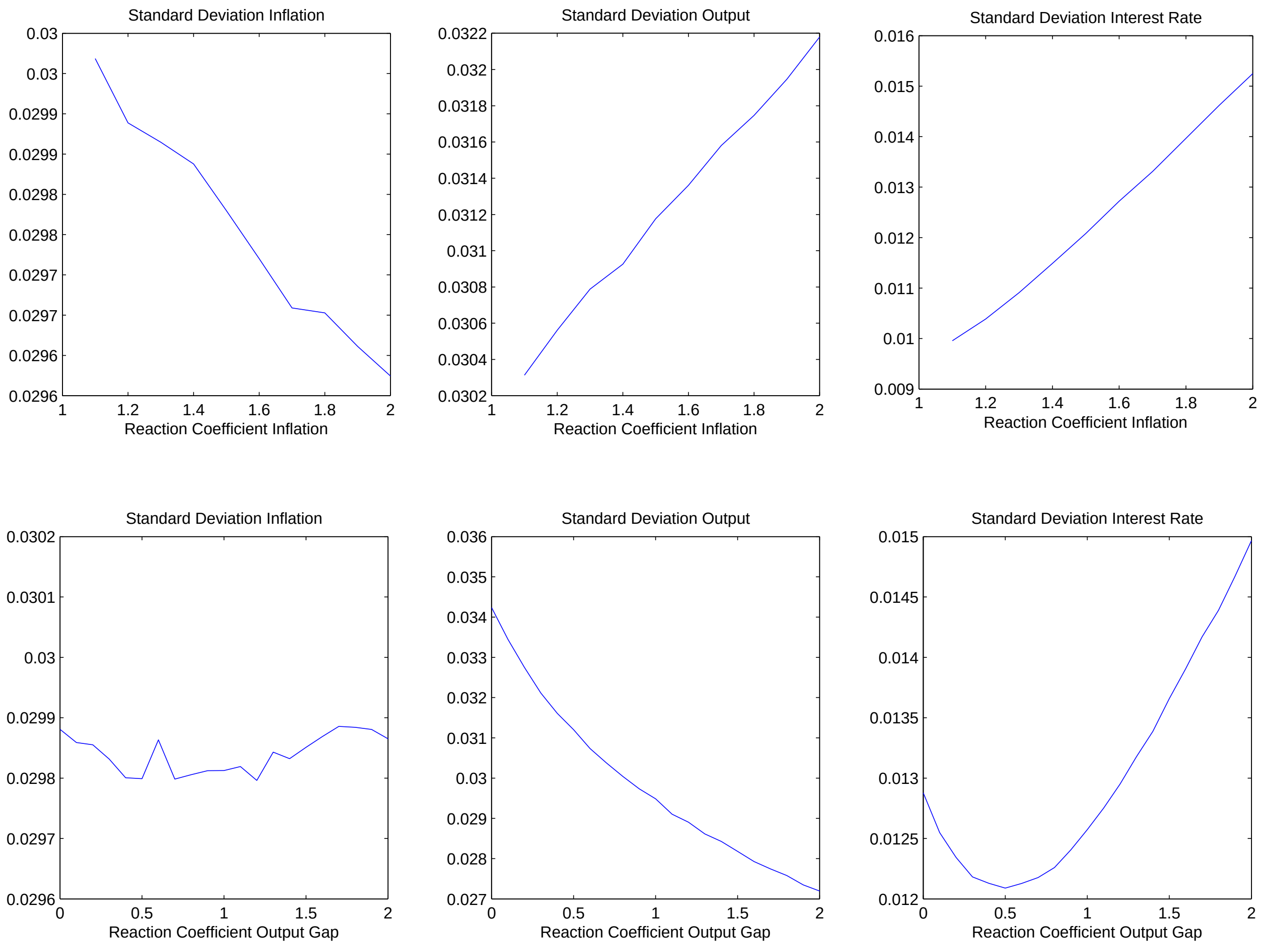


Figure 2.6: Impulse-Responses Across Taylor-Rule Coefficients of Inflation

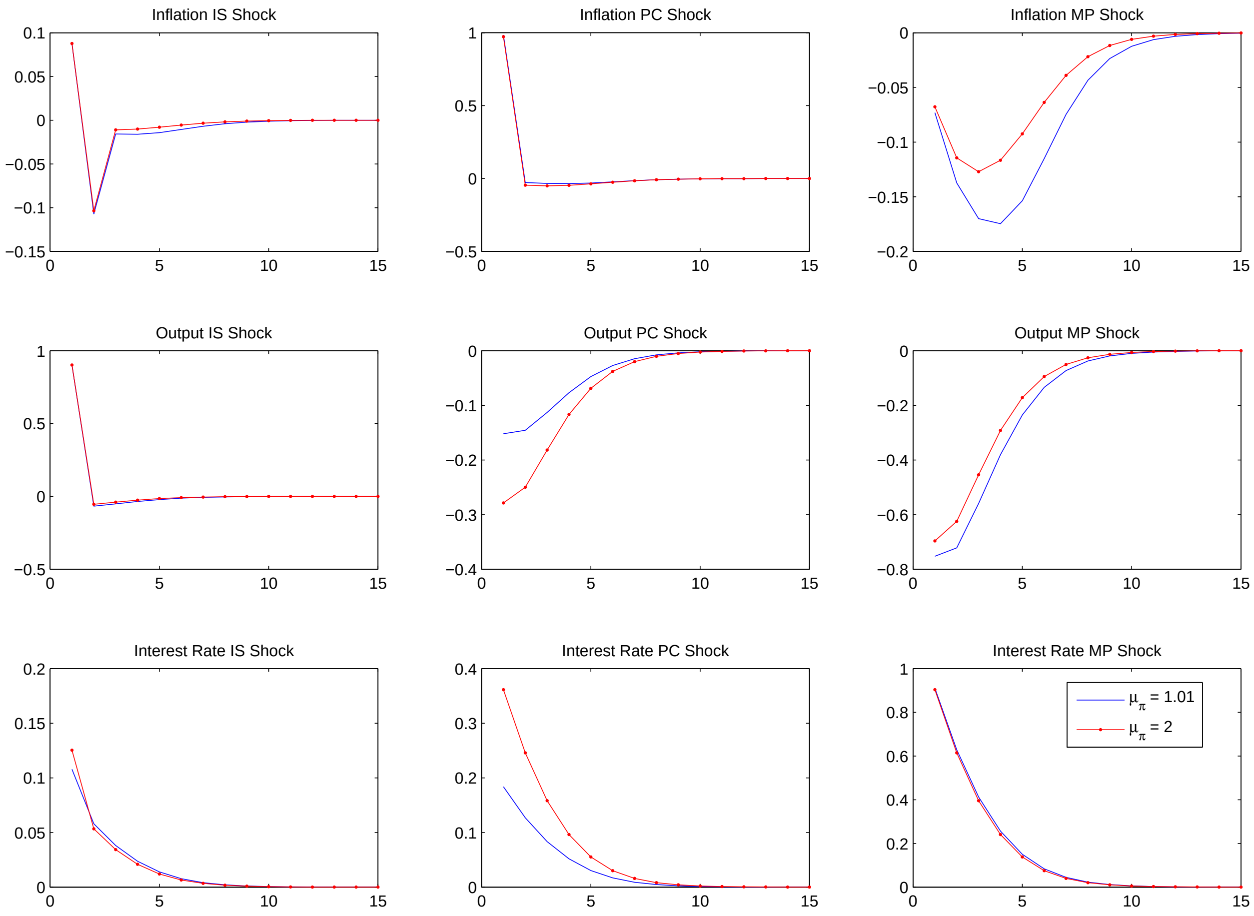
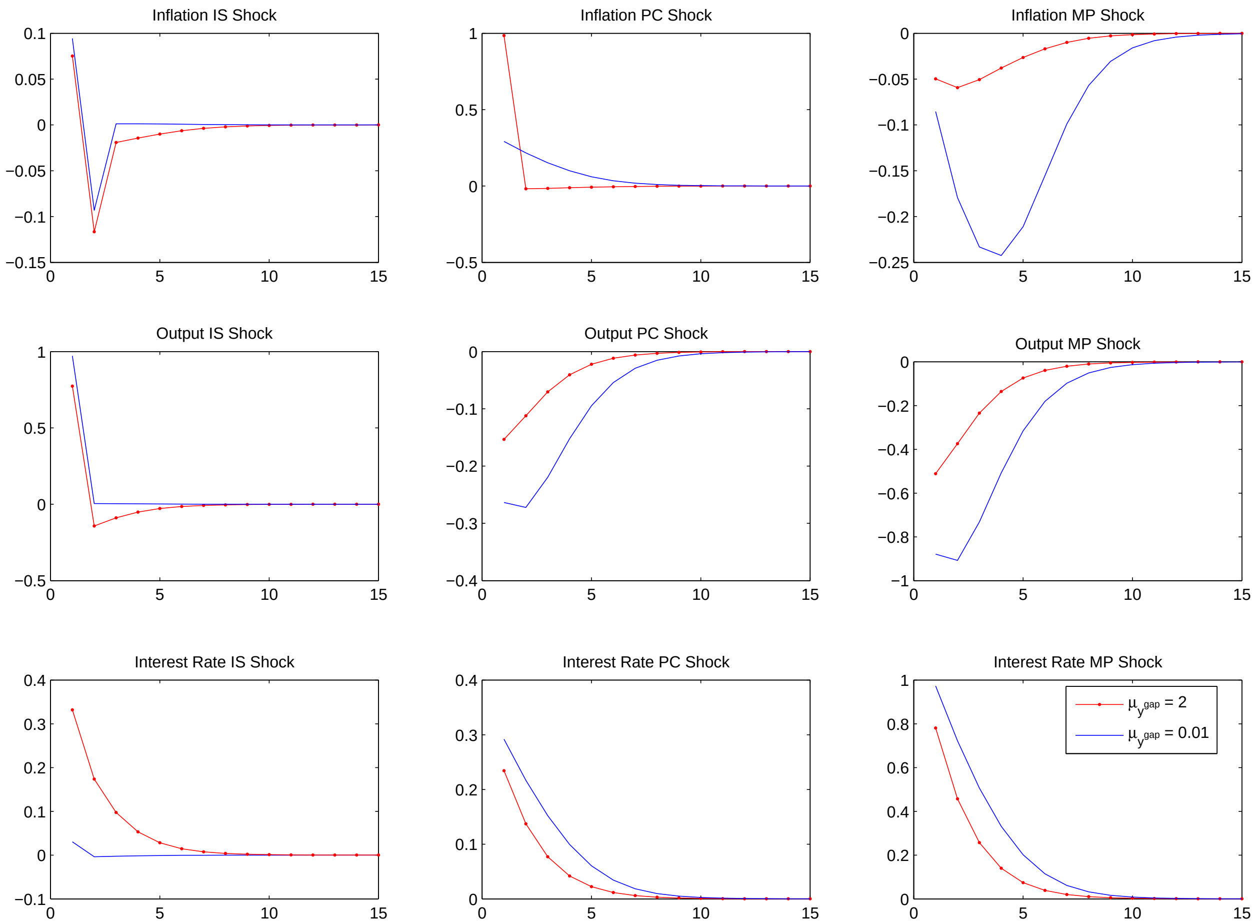


Figure 2.7: Impulse-Responses Across Taylor-Rule Coefficients of the Output Gap



Overall, it seems that even though $\mu_{y^{gap}}$ is not important for determinacy of the model, it is nevertheless relevant for a higher welfare in terms of less output variability. While $\mu_\pi > 1$ can only marginally reduce variability of inflation, output can be stabilized considerably by both keeping $\mu_{y^{gap}}$ relatively high and μ_π relatively low (providing the Taylor principle is fulfilled). This finding is in line with Adam (2007) and De Grauwe (2010), who report that the central bank can under certain conditions stabilize both inflation and output when targeting the output gap. One of these condition is that shocks have little persistence, a case that is assumed also in our model. By contrast, Branch et al. (2006) and Paciello and Wiederholt (2011) find that with endogenous inattentiveness or rational inattention, complete price stabilization is the optimal policy as it allows firms to pay less attention to pricing information, thus reducing responsiveness of the whole system to shocks. However, a different result could emerge if households were also subject to rational inattention in these models.

Finally, we compare impulse-responses obtained with the lower- and upper-bound values of μ_π and $\mu_{y^{gap}}$, setting the other parameter to its baseline calibration value, respectively. From Figure 2.6 we see that a higher coefficient on inflation in the Taylor rule will stabilize both output and inflation after a monetary policy shock, while the hump-shaped response of inflation is retained. However, this effect comes at the cost of a more severe recession in output after a cost-push shock, as interest rates are forced to increase more forcefully after a shock to inflation occurs. Hence, the short-run trade-off between stabilizing inflation and stabilizing output, analyzed for instance by Branch et al. (2006), becomes evident also in our model with endogenous sticky information.

Comparing impulse responses with $\mu_{y^{gap}} = 0.01$ and $\mu_{y^{gap}} = 2$ in Figure 2.7, again inflation and output are stabilized considerably in response to a monetary policy shock, if the central bank responds with a higher coefficient to changes in the output gap. In contrast to the result in Figure 2.7, the recession in output after a cost-push shock is also mitigated with a higher $\mu_{y^{gap}}$ in the Taylor rule, confirming our welfare result from Figure 2.5. However, a stronger reaction of the central bank to the output gap leads to a more pronounced increase of the nominal interest rate after a positive demand shock, causing output to undershoot so that a recession occurs after the shock. Hence, a high reaction coefficient on the output gap in the Taylor rule seems well suited to stabilize output and reduce recessions after a positive cost-push shock to inflation, but may cause a small recession after a positive demand shock due to an overly strong increase of the nominal interest rate.

2.5 Conclusion

We present a sticky information DSGE model where agents can choose each period between rational expectations and expectations under sticky information: Assuming that all agents know the relevant model, rational expectations produce perfect forecasts, but the new information set can only be obtained at a positive cost, the rationality cost. By contrast, outdated information reaches agents freely, but may lead to biased forecasts. Employing a switching mechanism by Brock and Hommes (1997), we thus derive a sticky information DSGE where the share of agents with rational expectations is endogenous and time-varying.

Results from numerical simulation suggest that the degree of inattentiveness varies between zero and one if the rationality cost corresponds to at least 50% of the mean squared forecast error under sticky information. However, even at zero costs, agents switch between forecasting rules as shocks hit the economy, emphasizing the relevance of a time-varying λ_t.

An important result of our model is the link it provides between models of sticky information and models of near-rationality à la Akerlof and Yellen (1985) and Akerlof et al. (1996, 2000): We find that the share of rational expectations is positively correlated with the variance of the variable to be forecasted. Hence, as in the models with near-rationality, agents form rational expectations if variability in the economy increases and can afford to use outdated information if variables remain relatively stable. The relevance of monetary policy for inflation expectactions is highlighted by the result that the share of agents with rational inflation expectations is additionally positively correlated with the variance of the interest rate. Thus, a more active monetary policy is interpreted as a signal to pay closer attention to inflation. This corresponds to our finding that in general agents are more rational with respect to output than with respect to inflation expectations and thus rely on the central bank to maintain a stable inflation rate.

Our model with endogenous λ_t preserves important results of the sticky information models in Mankiw and Reis (2002, 2007): We find that inflation has a hump-shaped response to a monetary policy shock, implying that the maximum impact of the shock occurs with a delay of some periods. This result is obtained even though we do not assume any autocorrelation in the shocks on aggregate output, inflation or nominal interest rates. Furthermore, we can confirm the finding by Meyer-Gohde (2009) that determinacy in sticky information models depends only on the Taylor rule coefficient of inflation and the model has a unique and stable equilibrium as long as the Taylor principle is fulfilled. With regard to the high persistence in simulated series for inflation and output, we can only reproduce results of Mankiw and Reis (2002, 2007) if we assume autocorrelated shocks like in Mankiw and Reis (2007). Hence, sticky information does not suffice to generate the degree of intertia observed empirically.

Analyzing optimal monetary policy in our DSGE with a constant share of agents using sticky information, we find that the Taylor principle is a necessary and sufficient condition for determinacy. However, output is stabilized best with a high coefficient on the output gap in the Taylor rule, which does not affect the inflation rate negatively. As long as the Taylor principle is fulfilled, varying the coefficients in the Taylor rule has only marginal effects on inflation stability, but increasing (decreasing) $\mu_{y^{gap}}$ (μ_{π}) will stabilize output. Furthermore, a stronger reaction of monetary policy to inflation will reduce the effect of a monetary shock on inflation (and, to a smaller degree, also output), but increases the recession after a cost-push shock to inflation. By contrast, a higher coefficient on the output gap will stabilize both output and inflation after monetary policy shocks and reduces the negative response of output after a cost-push shock. We thus conclude that optimal monetary policy should react more than one-to-one to changes in inflation, but nevertheless should not put too much weight on inflation relative to the output gap due to the short-run trade-off between inflation and the output gap. Thus, in terms of welfare our model suggests a role for output targeting in addition to an inflation target. Nonetheless, stabilizing inflation remains an important task for monetary policy, due to the strong link between heterogeneity in inflation expectations and monetary policy actions in our model.

Notwithstanding our results, there may exist further reasons for a relatively high coefficient on inflation in the Taylor rule, such as the prevention of time-inconsistency of monetary policy due to insufficient commitment, causing an inflationary bias. Here, we assume that the central bank always follows the mechanism given by the Taylor rule, such that problems of time-inconsistency cannot arise. Nevertheless, the analysis of our model under commitment and discretion of monetary policy would be an interesting aspect, which we leave for further research.

While Branch et al. (2006, 2009) solve for the optimal degree of inattentiveness by firms in the sticky information model of Ball et al. (2005), to the best of our knowledge this is the first approach allowing both firms and households to recursively choose between rational and sticky information expectations each period. In that sense, our model can analyze different aspects as we simulate the evolution of the degree of inattentiveness over time. Thereby, this chapter also stands in the tradition of models with heterogeneous expectations, where agents are generally assumed to choose between rational and non-rational expectations: For instance, De Grauwe (2010) finds that a fraction of agents forecasting with simple heuristics may cause endogenous inertia in inflation and output and that the central bank can reduce variability in both inflation and output when it targets output in addition to inflation. Similarly, Brazier et al. (2008) and Branch and Evans (2006, 2007, 2011) in their models with heterogeneous expectations also report a strong link between heterogeneous inflation expectations and monetary policy in the sense that heterogeneity in expectations may cause endogenous volatility in inflation, which in turn is mitigated once monetary policy targets inflation. In line with these models, we also find that the shares of rational agents react to changes in the volatility of the series forecasted. However, we are not able to reproduce feedback effects from the switching of forecasting rules to the model variables, since the switching mechanism operates after the model solution is found. In a companion model in chapter 3, we will thus incorporate feed-back from agents' switching decision to the model solution.

Chapter 3

Endogenous Persistence with Recursive Inattentiveness*

*This chapter is based on Dräger (2011a).

3.1 Introduction

Models in modern macroeconomics aim at reproducing stylized facts found in empirical data, while at the same time providing rigorous micro-foundations for macroeconomic relations. Stylized facts regarding aggregate inflation and output found in postwar U.S. data include their high persistence over time and the hump-shaped, delayed responses to a monetary policy shock.[1] However, as noted in Rudd and Whelan (2005), the New Keynesian Phillips curve with rational expectations cannot account for these empirical findings: With forward-looking expectations, the model cannot generate persistence in inflation as shocks are accounted for immediately. It can thus only be reconciled with empirical facts when including a lagged endogenous term. However, while appealing for instance to habit formation or rule-of-thumb price setting, this procedure remains ad hoc and is thus subject to the Lucas (1976) critique.

In their models with sticky information, Mankiw and Reis (2001, 2002, 2003, 2007) propose an alternative to fully rational expectations as in Muth (1961): They assume that all agents in the economy are rational, but underlie an exogenous probability λ of not being able to update to the most recent information set each period, due to the costs related to acquiring and processing new information. Only when they can update do agents form fully rational expectations, otherwise they remain inattentive towards new information and forecast with an outdated information set. The authors claim that their model replicates the stylized facts, yielding both persistence in aggregate data and hump-shaped responses to a monetary policy shock.

In chapter 2, we extend the sticky information model by endogenizing the probability of being able to update to the new information set, i.e. the share of agents with rational expectations each period. Employing a switching mechanism derived in a seminal paper by Brock and Hommes (1997), we allow agents to choose between costly rational expectations and forecasts under costless, but outdated information.[2] We assume that agents evaluate their mean squared forecast errors and switch to the rational predictor once losses from forecasting with outdated information become too high. Hence, the share of agents with rational expectations, λ_t, becomes endogenous and time-varying.

[1] Fuhrer and Moore (1995) as well as Gordon (1997) report strong inertia in U.S. inflation since the 1960s. Estimating VAR models, Christiano et al. (2005) and Rotemberg and Woodford (1997) find a hump-shaped response of both aggregate U.S. output and inflation after a monetary policy shock.

[2] Empirical evidence of persistent heterogeneity in inflation expectations and frequent switching between predictors is given in Maag (2010b) and Pfajfar and Zakelj (2009). Branch (2007) finds that survey data on U.S. inflation expectations is consistent with sticky information and a time-varying degree of inattentiveness.

We thus incorporate endogenous sticky information into a DSGE model with flexible prices, where we simulate agents' choice of predictors given equilibrium time paths for aggregate variables.

While we are able to reproduce the hump-shaped response of inflation to a monetary policy shock in the model in chapter 2, we do not find any significant persistence in simulated data for aggregate output and inflation. It thus seems that also in sticky information models, persistence can only be generated when adding either lagged endogenous variables or assuming autocorrelated shocks.[3] In this paper, we extend the model in chapter 2 by allowing for feedback from agents' predictor choice to the model equilibrium. As in Brock and Hommes (1997), the model is then solved recursively, where the optimal share of agents with rational expectations in the current period, λ_t, influences the model solution for the next period, when agents again decide between predictors, yielding λ_{t+1} and so on. We thus get a dynamic equilibrium path for aggregate output, inflation and nominal interest rates with recursive inattentiveness.

Allowing for feedback from agents' switching between forecasts to the model solution yields a highly persistent time series for aggregate output, without assuming autocorrelated demand or cost-push shocks or habit persistence i.e. rule-of-thumb pricing.[4] With respect to inflation, however, we find that although the model simulation implies a persistent trend, the inflation series shows rather high short-run volatility. This is due to the standard deviation of cost-push shocks on inflation, which we initially set equal to the standard deviation of demand shocks on output. Reducing the size of the cost-push shock generates more persistence in inflation and a higher degree of inattentiveness towards inflation.

Previous results from chapter 2 remain robust also with feedback from agents' switching to the model: Agents are still found to behave near-rationally as in Akerlof and Yellen (1985) and Akerlof et al. (2000), in the sense that they pay closer attention to recent changes in output and inflation if the variability of the forecasted variable rises as oth-

[3] A number of papers have analyzed robustness of the results in Mankiw and Reis (2001, 2002, 2003, 2007): Coibion (2006) evaluates robustness of responses to a monetary policy shock in a DSGE model with sticky information for both consumers and firms. The author finds that parameter specifications regarding real rigidities and the monetary policy objective function affect the result of hump-shaped impulse responses after a monetary policy shock. Trabandt (2007) finds that results of the initial sticky information model in Mankiw and Reis (2002) are robust in a larger DSGE model, but a hybrid New Keynesian Phillips curve fares equally well. By contrast, comparing estimates of DSGE models with sticky information or sticky prices, Andres et al. (2005) cannot reproduce the hump-shaped responses even with sticky information, while Korenok (2008) finds that the sticky price model statistically dominates the sticky information model.

[4] Note, however, that we allow for interest rate smoothing by the central bank and assume that the technology shock driving natural output $\hat{y}_t^n$ follows a first-order autoregressive process.

erwise losses from forecasting with outdated information are small. In addition to our earlier results, we find more interaction between inattentiveness towards output and inflation. Regarding impulse-responses of output and inflation to a monetary policy shock, we find that both show a hump-shaped response once the degree of inattentiveness is sufficiently high.

There are a number of approaches in the literature related to ours. While to our knowledge this is the first model analyzing endogenous inattentiveness over time, Branch et al. (2006, 2009) derive the optimal degree of inattentiveness by firms in a model with sticky information as in Ball et al. (2005). The authors show that a symmetric Nash equilibrium of inattentiveness exists, where firms minimize a quadratic loss function relating their firm-specific price under an individual degree of inattentiveness to the optimal price given some fixed economy-wide $\overline{\lambda}$. They assume that firms have to pay a fixed cost relative to λ^2 in order to process new information. Our approach differs from theirs in that we analyze agents' predictor choice over time and allow for feedback of agents' switching between predictors to the model solution. We are thus able to evaluate the effect of heterogeneous expectations on the dynamic equilibrium path of the economy.

Analyzing persistence of inflation with boundedly-rational inflation expectations, Lansing (2009) evaluates the hybrid New Keynesian Phillips curve with a time-varying parameter on lagged inflation. This parameter is given by the Kalman gain from a filter describing agents' optimal inflation forecast as an exponentially weighted moving average of past inflation, thus assuming a form of bounded rationality regarding inflation expectations. The author finds that his model set-up generates low-frequency swings in inflation from expectational feedback, resulting in a near-random walk behavior of inflation. Similarly, Ball (2000) presents a model with near-rational inflation expectations as in Akerlof and Yellen (1985): When forming expectations, agents optimally use past values of inflation, but ignore other variables that might affect inflation rates. This generates strong persistence in actual inflation, where the author notes that the model fits U.S. data well both for the period 1879–1914, when inflation was stationary, and for the period 1960–2000, when inflation was highly persistent. Furthermore, endogenous persistence in output and inflation is also generated in the DSGE model by De Grauwe (2008, 2010), where agents can choose between simple heuristic predictors in the switching mechanism proposed by Brock and Hommes (1997).

Analyzing the relation between professional inflation forecasts and those of the general public from survey data for the UK, Easaw and Golinelli (2010) find empirical evidence of near-rationality and inattention as in Akerlof et al. (1996, 2000). Assuming that the general public may absorb professional forecasts through the media and social transmission or ignore it, the authors report that professional forecasts are incorporated faster into own expectations when these lie below the reference value of the professional prediction. Inattentiveness by professional forecasters is further evaluated by Andrade and Le Bihan (2010) using the ECB Survey of Professional Forecasters. The authors find persistent disagreement between forecasters and evidence that new information is not incorporated into forecasts systematically, while forecasters also differ in their speed of updating. However, the data cannot be reconciled with a sticky information model because professional forecasters on the one hand seem to have strongly persistent forecast errors, while on the other hand disagreeing relatively little.

Finally, our model also relates to the literature on rational inattention founded by Sims (2003). Assuming that agents have a limited capacity to process information, only a fraction of all information that arrives can be incorporated into forecasts. Mackowiak and Wiederholt (2009, 2010) as well as Paciello and Wiederholt (2011) present DSGE models with rational inattention of firms, solving for the equilibrium degree of inattention and analyzing optimal monetary policy. Further approaches with rational inattention can be found in Adam (2007, 2009). While we assume in contrast to the literature on rational inattention that agents can form rational expectations once they pay the cost for it, our model incorporates aspects of rational inattention in that we assume agents are capable of assessing their forecast errors. Hence, agents are aware of some aggregate information, even if they consequently choose not to incorporate it into their expectations due to the related processing costs.

The remainder of the chapter is structured as follows: After the introduction, we briefly present the model in section 3.2. Results of the model simulations with recursive inattentiveness are given in section 3.3, where we analyze persistence of the variables, the nature of recursive inattentiveness, responses to monetary policy shocks and stability of the model. Finally, section 3.4 summarizes and concludes.

3.2 The Model

3.2.1 Model Equations

We analyze a model with endogenous sticky information, building on the one derived in chapter 2. Extending the models with sticky information by Mankiw and Reis (2001, 2002, 2003, 2007), we recursively derive the share of rational agents each period as an endogenous and time-varying expression. In that sense, our approach differs from the one in Branch et al. (2009), who solve for the constant equilibrium degree of inattentiveness by firms. The model equations are briefly reviewed here and we refer the reader to chapter 2 for detailed derivations.

Our model takes the form of a New Keynesian DSGE model with flexible prices and heterogeneous expectations. Heterogeneity arises because agents have the choice each period between paying the cost for the newest information set necessary to form rational expectations (what we term the 'rationality cost'), and using an older, costless information set to form expectations on output and inflation. While aggregate information may be publicly available, the rationality cost captures all costs related to acquiring and processing this information into agents' forecasts. Each period, thus, a share of agents has rational expectations, while the rest of the population is subject to sticky information, forecasting with information from the date when they last paid for new information. Note that we assume that all agents know the relevant model and are computationally able to form rational expectations, so that the only deviation from full rationality may be the use of outdated information. An expression for aggregate heterogeneous expectations is then derived as follows:

$$\widetilde{E}_t(x) \equiv \lambda_t E_t^{RE}(x) + (1-\lambda_t)E_t^{SI}(x) = \lambda_t E_t(x) + (1-\lambda_t)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}(x), \quad (3.1)$$

where E^{RE} and E^{SI} denote expectation operators under rational and sticky information, respectively, and λ_t is the time-varying share of rational agents in period t. Note that the sticky information expectation operator comprises expectations of all agents that do not update in period t, but instead use information from some time in the past. Their forecasts receive less weight, the older their information set is. Since all agents are computationally capable of producing rational forecasts, they switch to being rational as soon as they pay the rationality cost in a given period. Conversely, they belong to the sticky information group if they do not update and hence continue to use their information set from the previous period.

We then derive the Euler equation with heterogeneous expectations of households, where $\hat{x}$ denotes the deviation of x from its steady state:

$$\hat{c}_t = \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}), \quad (3.2)$$

Under the assumption that markets clear, output $\hat{y}_t$ is derived in a New Keynesian IS curve with heterogeneous expectations, where u_t denotes an i.i.d. demand shock:

$$\hat{y}_t = \lambda_t \left(E_t \hat{y}_{t+1} + \frac{1}{\sigma} E_t \pi_{t+1} \right) + (1 - \lambda_t)\overline{\lambda} \sum_{j=0}^{\infty} (1 - \overline{\lambda})^j E_{t-1-j} \left(\hat{y}_{t+1} + \frac{1}{\sigma} \pi_{t+1} \right)$$
$$- \frac{1}{\sigma} \hat{i}_t + u_t \tag{3.3}$$

Next, we derive an expression for aggregate prices $\hat{p}_t$ of firms, assuming flexible prices and the same heterogeneity with respect to expectations as for households:

$$\hat{p}_t = \widetilde{E}_t \left[\hat{p}_t + \psi \left(\hat{y}_t - \hat{y}^n_t \right) + e_t \right], \tag{3.4}$$

where e_t is an i.i.d. cost-push shock. The expression $(\hat{y}_t - \hat{y}^n_t)$ denotes the output gap, defined as the deviation of output $\hat{y}_t$ from the natural output $\hat{y}^n_t$. This is the optimal output that would occur under flexible prices and fully rational expectations and which is driven by an i.i.d. technology shock z_t:

$$\hat{y}^n_t = \frac{1 + \eta}{\sigma + \eta} \hat{z}_t \tag{3.5}$$

After some algebra, we get the sticky information Phillips curve with heterogeneous expectations from (3.4), where switching between predictors in the previous period influences the inflation rate π_t in the current period:

$$\pi_t = \frac{\psi \overline{\lambda}}{1 - \overline{\lambda}} (\hat{y}_t - \hat{y}^n_t) + \frac{\overline{\lambda}}{1 - \overline{\lambda}} e_t + \lambda_{t-1} E_{t-1} \left[\pi_t + \psi \Delta (\hat{y}_t - \hat{y}^n_t) + \Delta e_t \right]$$
$$+ (1 - \lambda_{t-1})\overline{\lambda} \sum_{j=0}^{\infty} (1 - \overline{\lambda})^j E_{t-2-j} \left[\pi_t + \psi \Delta (\hat{y}_t - \hat{y}^n_t) + \Delta e_t \right] \tag{3.6}$$

Finally, the model is closed by specifying that monetary policy sets nominal interest rates $\hat{i}_t$ according to a Taylor rule with interest rate smoothing, targeting actual inflation and the output gap as in Mankiw and Reis (2007):

$$\hat{i}_t = \mu_i \hat{i}_{t-1} + (1 - \mu_i) \left(\mu_\pi \pi_t + \mu_{y^{gap}} (\hat{y}_t - \hat{y}^n_t) \right) + \eta_t, \tag{3.7}$$

where η_t denotes an i.i.d. monetary policy shock. An expression for the time-varying degree of inattentiveness captured by the share of rational agents, λ_t, is then derived by adapting the switching mechanism derived in a seminal paper by Brock and Hommes

(1997). This approach assumes that agents continuously evaluate the accuracy of their forecasts and switch to being rational once the losses from forecasting with outdated information exceed the costs for the new information set. Conversely, if the gains from rational forecasts are not sufficient to outweigh the rationality costs, agents refrain from using rational expectations and switch to forecasting with sticky information by not updating in the current period.

In order for agents to be able to evaluate their forecast accuracy, we assume that some information on aggregate variables arrives continuously, but due to the related costs agents may choose not to process it into their forecasts. In that sense, our definition of sticky information differs slightly from the one in Mankiw and Reis (2001, 2002, 2003, 2007) and is closer to the concept of rational inattention in Sims (2003). Nevertheless, deriving microfoundations for the sticky information model, Reis (2006b) also finds that the optimal degree of inattentiveness is a function of the volatility of shocks as well as the difference between profits under full or sticky information, thus using aggregate conditions to derive a fixed λ.

In line with the literature on heterogeneous expectations and also the approach in Branch et al. (2009), we define agents' mean squared forecast errors as the metric of forecast accuracy. These are given with respect to the variable $\hat{x}$ with rational or sticky information by the following expressions:

$$U_t^{RE} = -\sum_{k=0}^{\infty} \left[\omega_k \left(\hat{x}_{t-k} - E_{t-k-1}\hat{x}_{t-k}\right)^2 + K^{RE}\right] \tag{3.8}$$

$$U_t^{SI} = -\sum_{k=0}^{\infty} \left[\omega_k \left(\hat{x}_{t-k} - \overline{\lambda} \sum_{j=k-1}^{\infty} (1-\overline{\lambda})^j E_{t-j-1}\hat{x}_{t-k}\right)^2\right], \tag{3.9}$$

where K^{RE} is the rationality cost of obtaining up-to-date information, which has to be paid each period. We define K^{RE} relative to the mean squared forecast error under sticky information and assume a baseline value of 50%.[5] The weights ω_k are assumed to be geometrically declining and sum to one, defined as $\omega_k = (1-\rho)\rho^k$, with $0 < \rho < 1$ measuring the degree of agents' memory of past mean squared forecast errors.[6]

Finally, following Brock and Hommes (1997), the time-varying degree of inattentiveness is given by a multinomial logit map, defining the probability of choosing the

[5] Robustness of the model with respect to changing values of K^{RE} is analyzed in chapter 2. Generally, a higher rationality cost induces a lower share of agents with rational expectations and *vice versa*.

[6] Note that we assume that agents inherit knowledge of the past forecast accuracy of their predictor when switching between forecasts under fully rational or sticky information.

rational predictor as a function of its relative desirability, i.e. its measure of forecast accuracy U^{RE}. This approach is frequently used in discrete choice theory, see Manski and McFadden (1981).

Since in our model agents form expectations regarding output and inflation, we define two switching mechanisms regarding the share of agents with rational output and inflation expectations, respectively. This allows us to account for the different effects of shocks in the economy on output and inflation and their different weights in the central bank's Taylor rule. We thus get for the time-varying degree of inattentiveness regarding output, λ_t^y, and inflation, λ_t^π:

$$\lambda_t^y = \frac{\exp(\gamma U_{y,t}^{RE})}{\exp(\gamma U_{y,t}^{RE}) + \exp(\gamma U_{y,t}^{SI})} \tag{3.10}$$

$$\lambda_t^\pi = \frac{\exp(\gamma U_{\pi,t}^{RE})}{\exp(\gamma U_{\pi,t}^{RE}) + \exp(\gamma U_{\pi,t}^{SI})}, \tag{3.11}$$

where the parameter γ is called the 'intensity of choice' and measures the degree to which agents will be influenced in their choice of predictor by its past forecasting performance.

3.2.2 Equilibrium Dynamics

The model solution is found recursively over the simulation horizon: As in chapter 2, we use the algorithm by Meyer-Gohde (2010) to numerically solve for the system of linear rational expectation equations with an infinite sum of lagged expectations. The algorithm combines a Generalized Schur Decomposition to solve for the undetermined coefficients of the MA(∞) recursive law of motion with an approximation to the infinite sum of lagged expectations by calculating matrices of limiting coefficients. The model solution is different from the one in chapter 2, however, in that we allow for feedback from agents' switching decision between expectation operators to the evolution of the model economy. As in Brock and Hommes (1997), the model is thus solved recursively over time, yielding simulated time paths for aggregate variables and time-varying inattentiveness.

Specifically, the timing of events is as follows: Starting from an initial simulation of the model with fixed degree of inattentiveness, agents evaluate the performance of their forecast model in period t and decide whether to switch predictors. The degree of inattentiveness is then found via the multinomial logit map given in equations (3.10) and (3.11). The new values of λ_t^y and λ_t^π are incorporated into the model equations and influence its solution in the next period. Given the new solution and an exogenous vector of shocks, the model simulation for period $t+1$ is found. Again, agents evaluate their forecast performance and decide on their predictor, thus defining the degree of inattentiveness λ^y_{t+1} and λ^π_{t+1}. These feed back into the model solution for period $t+2$ and so forth.

The existence of an equilibrium with endogenous inattentiveness is proven by Branch et al. (2009) for a model with a sticky information price setting curve as in Ball et al. (2005). The authors model endogenous inattentiveness as firms' optimal choice of λ via a loss function describing expected profit losses when deviating from an economy-wide degree of inattentiveness $\overline{\lambda}$. The equilibrium λ^* is then given as a symmetric Nash equilibrium: It is defined by the fixed point of the map describing firms' best-response function as the value of λ that minimizes the loss function and the costs of updating defined relative to λ^2. The authors show that a symmetric Nash equilibrium of this kind exists and highlight the fact that multiple equilibria may be present.

For the case of models with recursively time-varying shares of agents using a particular predictor, Brock and Hommes (1997) analyze equilibrium dynamics in a cobweb model, where agents choose between rational and adaptive expectations. The authors find that if a cost to rational expectations is introduced and if the intensity of choice, γ, is sufficiently high, complicated equilibrium dynamics may arise. Specifically, for high values of γ, the system is close to or has a homoclinic orbit and corresponding strange attractors.

A homoclinic orbit is defined as the intersection of the stable and the unstable manifold of the steady-state saddle point equilibrium. If additionally the Jacobian of the saddle point at the homoclinic orbit has two eigenvalues whose product is absolutely smaller than one, there exist values around the homoclinic orbit for which the system has a strange attractor. This implies a complex and potentially chaotic long-run dynamic behavior of the system.

From an economic perspective, this means that for sufficiently high values of γ, agents have a high propensity to switch to their optimal predictor each period. In the cobweb model with rational and adaptive expectations by Brock and Hommes (1997), if the economy is in a stable phase, most agents will use the cheap adaptive predictor. This causes prices to move away from their steady state and an unstable phase begins. In order to stabilize profits, agents will then be willing to pay the costs for rational expectations, which in turns moves prices back to the steady state as most agents switch to the rational predictor. The equilibrium dynamic path of the model thus consists of irregular switching between phases where most agents are adaptive and prices fluctuate and phases with predominant rationality and prices close to the steady state.[7] We analyze dynamic equilibrium paths of our model with endogenous sticky information in section 3.3.4.

3.3 Results

In this section we present results from numerical simulations of the model with endogenous and time-varying inattentiveness. We define the model as quarterly and simulate over 1500 periods, where the first 500 periods initialize the model and produce lagged expectations and are dropped consequently. Calibration parameters are chosen in line with those in chapter 2 and correspond closely to the calibration in McCallum (2001), where the model is defined as quarterly. The exact parameters are summarized in Table B.1 in the appendix in chapter B. We refer the reader to the previours chapter 2 for a discussion of the parameters and of alternative calibrations. In line with the model in chapter 2, we initially set the standard deviation of demand and cost-push shocks on output and inflation equal at $\tau_y = \tau_\pi = 0.03$ percentage points. Additionally, we assume no autocorrelation in the shocks, except for the technology shock on natural output $\hat{y}_t^n$.

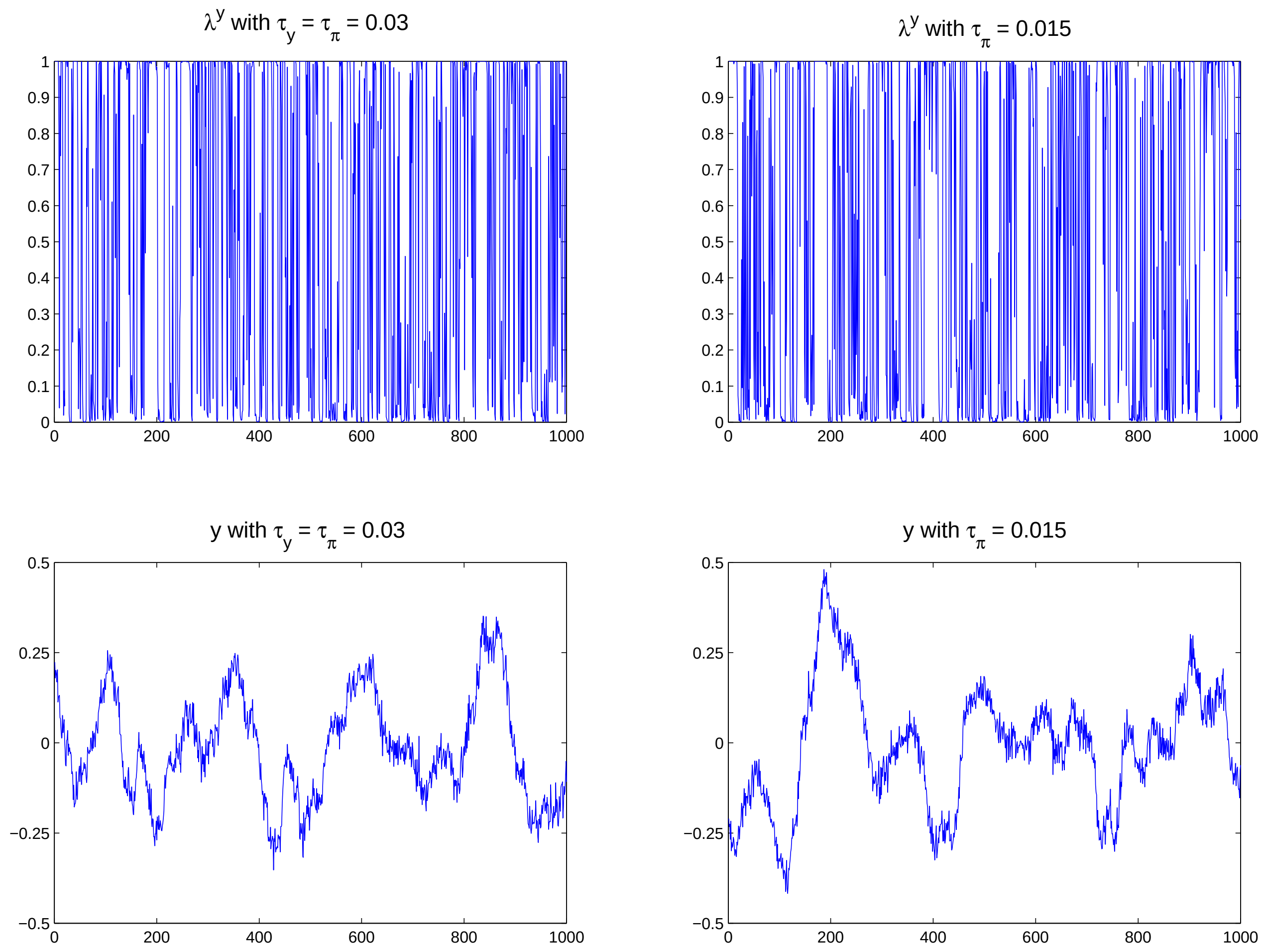
3.3.1 Endogenous Persistence

Allowing for feedback from agents' decision between rational or sticky information expectations, we simulate equilibrium time paths of output, inflation and the nominal interest rate. As described in the previous section, these should be understood as dynamic equilibria, which are computed recursively over time as the equilibrium response of the model economy to shocks and time-varying degrees of inattentiveness. Dynamic equilibrium time paths of output $\hat{y}$ and inflation π are shown together with the time-varying share of agents having rational output and inflation expectations, respectively, in Figures 3.1 and 3.2.

From Figure 3.1 we see that allowing for feedback from agents' switching decision to the model economy produces considerable persistence in the time path of output, as the share of agents with rational output expectations fluctuates between zero and one. This is important because it suggests that the model is able to generate strong inertia of aggregate variables simply by endogenizing the choice of predictor each period.

[7] Note that for $\gamma = +\infty$, in each period all agents choose the optimal predictor so that the system converges to a (locally unstable) saddle point equilibrium steady state, see Brock and Hommes (1997).

Figure 3.1: Output and Time-Varying Inattentiveness across Modelspecifications



Hence, it seems that our model with endogenous and time-varying inattentiveness can reproduce an important stylized fact, namely the persistence of aggregate output usually found in empirical data, see for instance Fuhrer and Moore (1995) and Gordon (1997). Note, however, that this result is to some degree influenced by our assumption of a first-order autocorrelated technology shock on natural output $\hat{y}_t^n$. Nevertheless, this seems to be a reasonable assumption, given that the model is specified as quarterly.

Regarding the dynamic equilibrium path of inflation, Figure 3.2 shows that simulating the model with the initial calibration yields a path for inflation showing a persistent trend, but rather high short-term variance. This seems at odds with empirical findings of a relatively high degree of persistence also in (quarter-on-quarter) inflation, albeit being somewhat smaller than that of aggregate output. Furthermore, while we initially calibrated the standard deviations of the shocks on output and inflation to be equal, several studies assume cost-push shocks on inflation to be smaller in absolute size than the demand shocks on output. For instance, in what we take to be our baseline calibration, McCallum (2001) sets $\tau_\pi = 0.002$ and $\tau_y = 0.03$. Therefore, we reduce the size of the cost-push shock, setting $\tau_\pi = 0.015$ percentage points.[8] The adjusted calibration gives a significantly more persistent time path of equilibrium inflation. While the share of agents with rational inflation expectations, λ_t^π still deviates between zero and one, we see that the smaller size of the cost-push shock leads agents to increasingly opt for the cheaper sticky information predictor.

Table 3.1: Descriptive Statistics of Simulated Variables

Variable	Model	Standard Deviation	AR(1) Coefficient
$\hat{y}$	$\tau_y = \tau_\pi = 0.03$	0.1587	0.9776
	$\tau_\pi = 0.015$	0.1580	0.9767
π	$\tau_y = \tau_\pi = 0.03$	0.0416	0.0530
	$\tau_\pi = 0.015$	0.0264	0.4594
$\hat{i}$	$\tau_y = \tau_\pi = 0.03$	0.0372	0.9361
	$\tau_\pi = 0.015$	0.0355	0.9757

Note: Values from simulating the model 1000 times over 1000 periods.

[8] We chose the adjusted value of τ_π so that the calibration would yield a degree of persistence of inflation similar to that found in U.S. data, while at the same time producing a time-varying degree of inattentiveness between zero and one. A higher τ_π will lead to less persistence and more switching, while a lower τ_π will increase inertia of inflation, but leads agents to decreasingly choose the expensive rational predictor.

Figure 3.2: Inflation and Time-Varying Inattentiveness across Modelspecifications

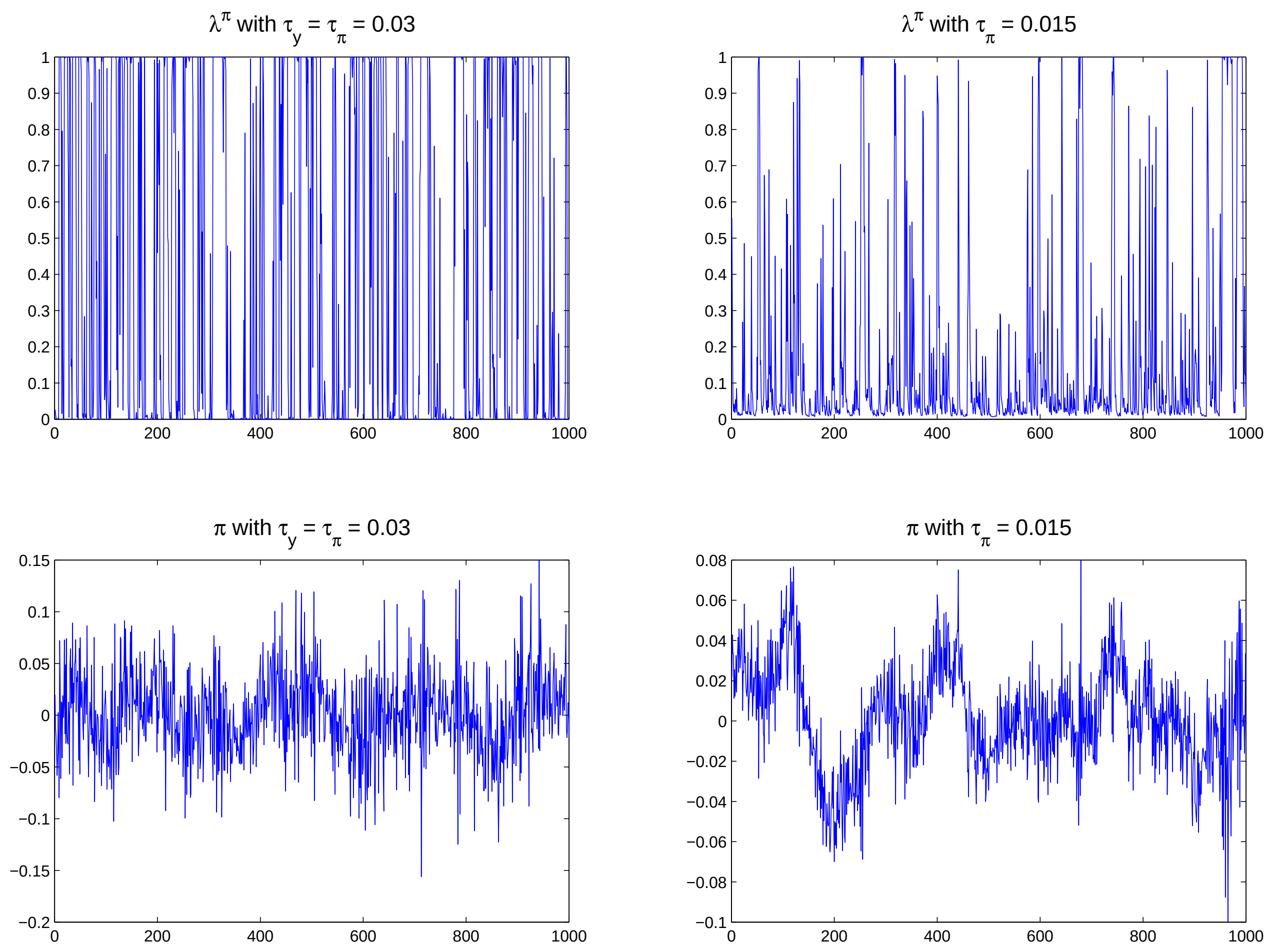


Table 3.1 summarizes sample statistics of aggregate output, inflation and nominal interest rates across model specifications. With the initial calibration, both output and nominal interest rates are highly persistent and close to a random walk, while we find no significant autocorrelation in inflation due to the high degree of short-term variation. By contrast, reducing the standard deviation of cost-push shocks to $\tau_\pi = 0.015$ increases persistence of inflation significantly with a serial correlation coefficient of about 0.5.

3.3.2 Recursive Inattentiveness

After analyzing dynamic equilibrium time paths for aggregate variables of the model, we turn to evaluating recursive inattentiveness. Table 3.2 presents sample statistics of λ_t^y and λ_t^π for the two cost-push shock calibrations.

Table 3.2: Time-Varying Inattentiveness

Variables	λ^y	λ^y	λ^π	λ^π
	$\tau_y = \tau_\pi = 0.03$	$\tau_\pi = 0.015$	$\tau_y = \tau_\pi = 0.03$	$\tau_\pi = 0.015$
Min.	0.0005	0.0005	0.0000	0.0069
Max.	1.000	1.000	1.000	1.000
Mean	0.5616	0.5360	0.4445	0.2198
Std.	0.4425	0.4429	0.4628	0.2751
Av. Cycle	2.616	2.608	2.992	1.413

Note: Mean values from simulating 1000 times over 1000 periods.
The average cycle length is calculated in quarters.

We find that the share of agents with rational output expectations is not affected significantly by changing the size of the cost-push shock on inflation. Overall, agents deviate between full rationality and full inattentiveness regarding output, while on average about 50% of agents use either predictor for an average of 2.6 quarters before switching again.[9] Regarding the degree of inattentiveness towards inflation, reducing the size of the cost-push shock lowers the mean share of agents with rational inflation expectations from about 44% to about 22%.[10] This is not surprising, as a smaller shock on infla-

[9]The average cycle length of switching between predictors is defined as the average time that λ_t^y or λ_t^π do not deviate from their values in the previous period by more than a threshold of 0.001 and is calculated in quarters.

[10]Note that our mean values of λ^y and of λ^π with the larger cost-push shock fit well with empirical estimations of the overall probability of updating sticky information for U.S. data of λ between 0.44 and 0.71 in Kiley (2007). By contrast, the mean value of 0.22 obtained for λ^π with a smaller cost-push shock is closer to estimates of about 0.3 found in Carroll (2003) for the U.S. and in Döpke et al. (2008a,b) for a panel of European countries.

tion will make the inexpensive sticky information predictor more attractive compared to costly rational expectations. However, a smaller τ_π also reduces the average switching frequency regarding inflation predictors from nearly 3 to 1.4 quarters. Comparing these results to the ones obtained in chapter 2, it seems that allowing for feedback from agents' predictor choice to the model induces agents to switch more frequently, especially with respect to inflation expectations. Nevertheless, the result that on average agents seem to be more rational with respect to output than to inflation remains robust. This is due to the fact that as agents know that the central bank places a larger weight on stabilizing inflation relative to the output gap, they can 'delegate' rationality to the central bank and thus concentrate more on current output movements.[11]

Table 3.3: Time-Varying Inattentiveness and Macroeconomic Variables

Correlation with	λ_t^y $\tau_y = \tau_\pi = 0.03$	λ_t^y $\tau_\pi = 0.015$	λ_t^π $\tau_y = \tau_\pi = 0.03$	λ_t^π $\tau_\pi = 0.015$
Level π_t	-0.001	0.000	0.000	0.007
Variance π_t	0.064	0.098	0.603	0.654
Level $\hat{y}_t$	-0.001	0.000	0.000	-0.007
Variance $\hat{y}_t$	0.310	0.307	0.016	0.008
Level $\hat{i}_t$	0.000	0.000	0.000	0.008
Variance $\hat{i}_t$	0.108	0.103	0.444	0.479

Note: Values from simulating 1000 times over 1000 periods.

Finally, we analyze the relation between agents' choice of predictors and the macroeconomic conditions in the model economy. Table 3.3 presents correlation coefficients of λ_t^y and λ_t^π with the level and variance of output, inflation and nominal interest rates. In line with our results in chapter 2, we find that the degree of attentiveness is strongly correlated with the variance of the variable to be forecasted. In that sense, agents in our model behave near-rationally as in Akerlof and Yellen (1985) and Akerlof et al. (2000). Thus, they increasingly opt for costly rational expectations as the variability of the forecasted variable rises, and remain inattentive towards new developments in the variable otherwise. Interestingly, allowing for feedback from predictor choice to the economy does not significantly affect the degree of correlation between λ_t^y and $Var(\hat{y}_t)$, while the correlation of λ_t^π with $Var(\pi_t)$ rises from about 0.4 to about 0.6.

Also in line with our results in chapter 2, attentiveness towards inflation is positively correlated with the variance of nominal interest rates, suggesting a strong link between

[11]This effect is reduced as the Taylor rule coefficients μ_π and $\mu_{y^{gap}}$ converge, see results in chapter 2.

monetary policy and inflation: As monetary policy becomes more active, agents interpret this as a signal to pay closer attention to recent inflation developments. However, once recursive inattentiveness influences dynamic equilibrium outcomes of the model, we find that also attentiveness towards output is increasingly influenced by variation in inflation and nominal interest rates. Although this effect is smaller than the link between inflation expectations and interest rates, it shows that the dynamics of the model become more complex once we allow for feedback from endogenous inattentiveness to the model. Especially with $\tau_\pi = 0.015$, the correlation between λ_t^y and the variances of inflation and of nominal interest rates is close to 10%.

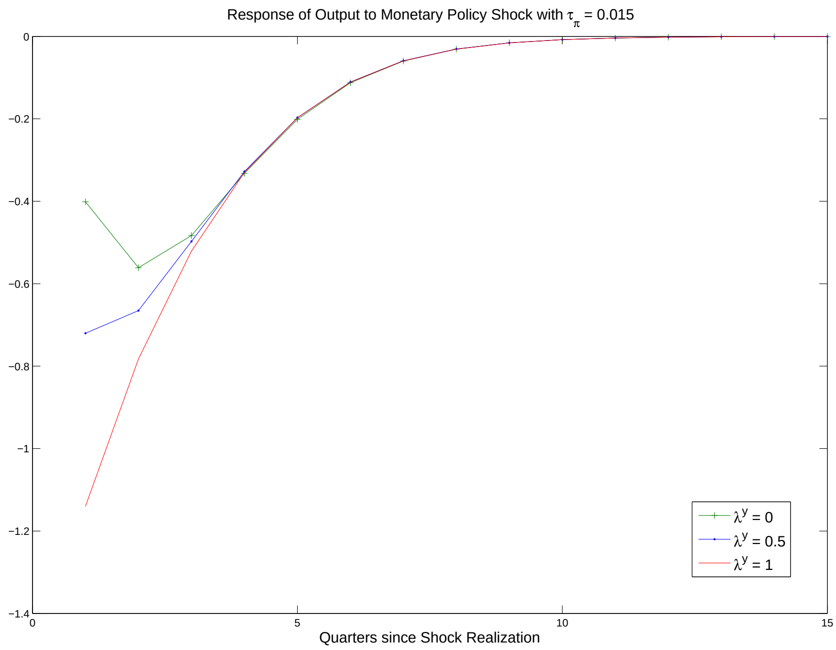
3.3.3 Monetary Policy with Recursive Inattentiveness

After evaluating the statistical properties of simulated series for aggregate variables and recursive inattentiveness, we turn to analyzing the effects of a monetary policy shock. Specifically, we are interested in whether the model can generate the delayed, hump-shaped, responses of both output and inflation after a monetary policy shock found empirically for instance in Christiano et al. (2005) and Rotemberg and Woodford (1997). Since our model has a dynamic equilibrium with time-varying parameters λ_t^y and λ_t^π, overall impulse-responses in terms of the $MA(\infty)$-coefficients cannot be derived, since the MA-representation of the model changes each period. Therefore, we approximate effects of a monetary policy shock on output by fixing the share of agents with rational inflation expectations at $\lambda^\pi = 0.5$ and letting the share of agents with rational output expectations vary between zero and one. Conversely, the effect of a monetary policy shock on inflation is simulated for varying values of λ^π, keeping λ^y fixed at 0.5.[12]

Figure 3.3 shows impulse responses of output to a one-standard-deviation monetary policy shock for varying degrees of inattentiveness towards output. Even with full rationality ($\lambda^y = 0$), we see that an unexpected increase in nominal interest rates causes output to fall below its steady state value for about 10 quarters. This is because the model still assumes inattentiveness towards inflation, which leads to an overall slower adjustment process after the shock. However, even though the adjustment process shows some inertia, we cannot generate a hump-shaped response of output to the monetary policy shock. Setting the degree of inattentiveness towards output at 50%, the negative response of output to the shock is considerably smaller, as only half of the population learns about it in the current period, and the adjustment process becomes more persistent. Finally, assuming that all agents use information from the last period or older

[12] All simulations are carried out with $\tau_\pi = 0.015$.

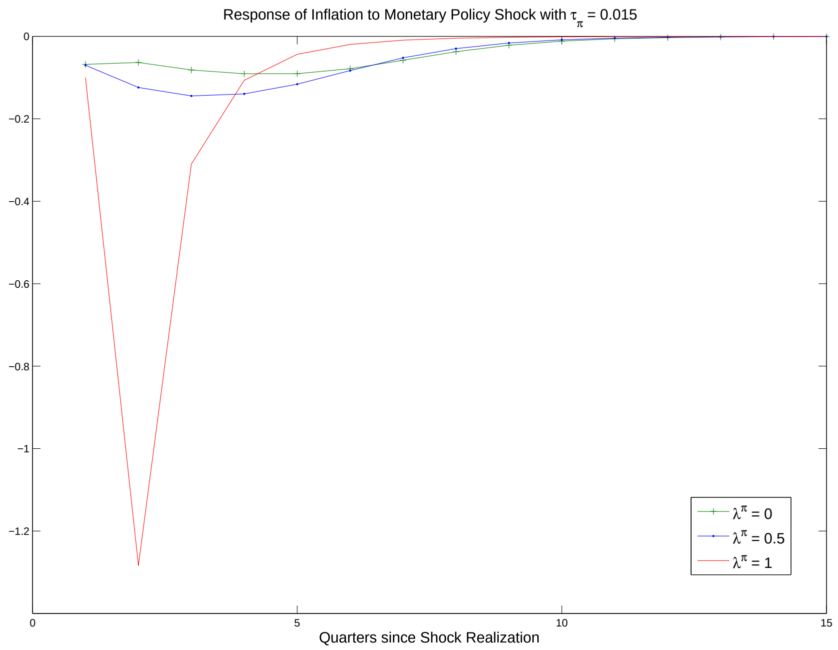
Figure 3.3: Impulse Responses of Output to a Monetary Policy Shock



($\lambda^y = 1$), we are able to replicate the hump-shaped response of output to a monetary policy shock found in empirical data. The negative effect of the monetary policy shock is mitigated even further and has its strongest impact in the second quarter after the occurrence of the shock.

Impulse responses of inflation to a one-standard-deviation monetary policy shock are presented in Figure 3.4. Similar to our results for impulse-responses of output, with full rationality towards inflation ($\lambda^\pi = 0$) a positive shock to nominal interest rates reduces inflation significantly below its steady state with a gradual adjustment of about 7 quarters. Note that the strongest effect of the shock materializes in the second, not the first, period after the shock. This is because inflation in the sticky information Phillips curve with flexible prices is affected by inattentiveness in the previous period, as shown in equation (3.6). In contrast to our results for impulse-responses of output, we find a hump-shaped response of inflation to a monetary policy shock already when assuming that 50% of all agents forecast with sticky information. The negative effect of the unexpected increase in interest rates is reduced considerably, and inertia of the adjustment process is increased. Finally, with all agents forecasting inflation under sticky information, the hump-shaped response is even more pronounced: A monetary policy shock has its strongest impact on inflation up to 5 quarters after the shock. Overall, we

Figure 3.4: Impulse Responses of Inflation to a Monetary Policy Shock



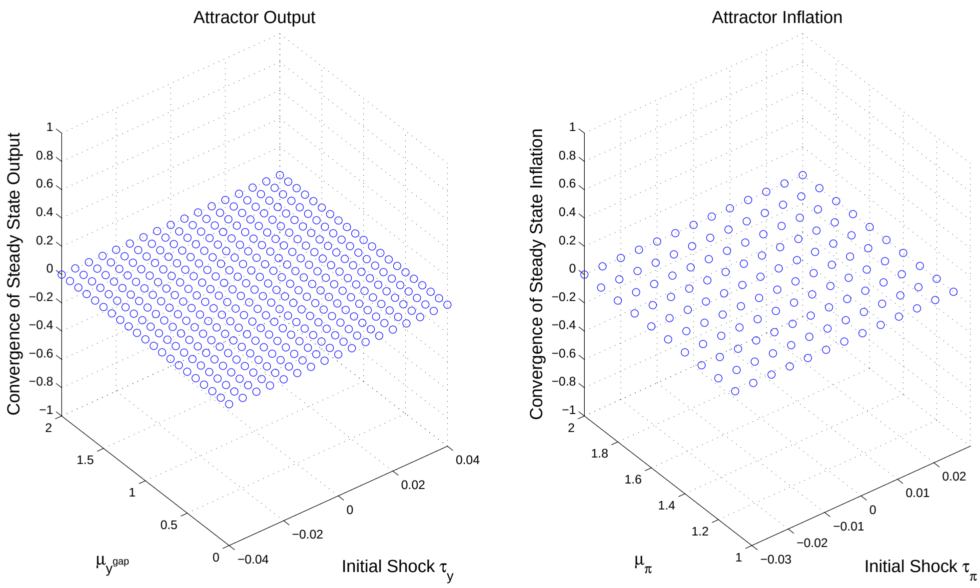
thus find that hump-shaped impulse-response functions can be reproduced for output and inflation when all agents use the sticky information predictor. Additionally, a hump-shaped response of inflation is found even for $\lambda^{\pi} = 0.5$. In periods of relatively high inattentiveness by agents, a monetary policy shock will thus have more persistent effects.

3.3.4 Stability of the Model

After analyzing equilibrium dynamics of aggregate variables and recursive inattentiveness in our model with endogenous sticky information, we check for stability of the steady state and evaluate conditions for determinacy of the model.

As noted in Brock and Hommes (1997), endogenous switching between predictors in a dynamic equilibrium may lead to complex and potentially chaotic dynamics if the intensity of choice, γ, is sufficiently high. This may result in the occurrence of a homoclinic orbit with strange attractors, implying that the system does not converge to its steady state after an initial shock. In order to check for the existence of strange attractors, we run a number of simulations, where either output or inflation are subjected to an initial shock. After the shock, the model is simulated for 1000 periods and we collect the final attractors that output, inflation, interest rates and the shares of rational agents converge to. Figure 3.5 plots attractors of output and inflation for simulations across a range of Taylor rule coefficients $\mu_{y^{gap}}$ and μ_π and a range of initial shocks with standard deviations τ_y and τ_π.

Figure 3.5: Steady State Attractors of Output and Inflation



From Figure 3.5 we see that both output and inflation converge to their steady states of zero after being subjected to a range of positive and negative shocks. This result remains robust across changing values of Taylor rule coefficients for the output gap ($0 \leq \mu_{y^{gap}} \leq 2$) and inflation ($1 < \mu_\pi \leq 2$), where we respect the Taylor principle by ensuring that monetary policy reacts more than one-for-one to changes in inflation. Convergence to the zero steady state occurs also for nominal interest rates and the shares of rational agents converge to values close to zero.[13] We thus find that our model with endogenous sticky information does not show any system-inherent chaotic long-run dynamics, as after an initial shock all aggregate variables return to their steady state values and agents thus opt for a constant degree of inattentiveness. Hence, although the dynamic equilibrium paths of the aggregate variables and recursive inattentiveness in our model seem similar to the switching behavior described in Brock and Hommes (1997), dynamics die out quickly if the system is no longer subject to exogenous shocks. Our result is in contrast to De Grauwe (2008, 2010)'s DSGE model where agents choose

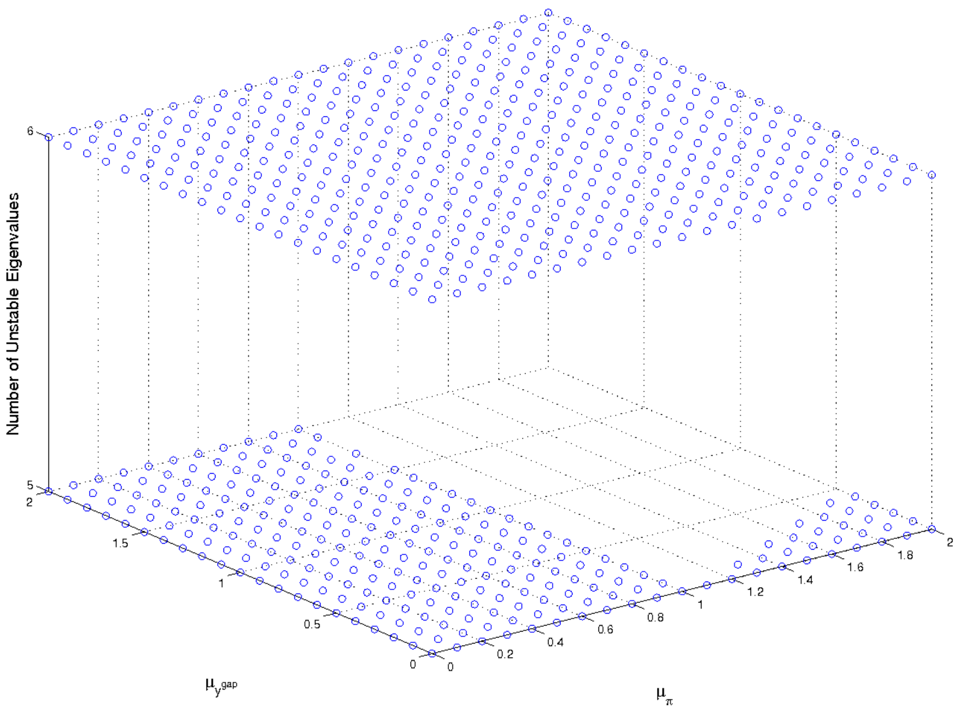
[13]We omit graphical representation of these results for reasons of space limitations, but the results can be obtained from the author upon request.

between simple heuristic predictors: The author finds that chaotic strange attractors may arise for sufficiently large shocks on output and inflation if monetary policy is not credible, resulting in endogenous cyclical movements of output and inflation.

Finally, we evaluate determinacy of the model across a range of Taylor rule coefficients. In chapter 2, we analyze determinacy with a fixed degree of inattentiveness given by $\lambda^y = \lambda^\pi = 0.5$, since it is assumed that agents' choice between predictors does not influence the model solution. Given a constant share of agents with rational expectations, our model can reproduce the result in Meyer-Gohde (2009) who finds that determinacy in a sticky information model depends solely on the Taylor principle.

Because we assume that in the limit all agents have rational expectations, we can use the well-known eigenvalue accounting method by Blanchard and Kahn (1980) to check for the existence of a unique and stable solution to the model. Here, we thus evaluate the number of unstable eigenvalues across Taylor rule coefficients for varying degrees of inattentiveness towards inflation and output.

Figure 3.6: Determinacy across Taylor Rule Coefficients



Simulated with $\tau_\pi = 0.015$.

Figure 3.6 plots the number of unstable eigenvalues of simulations with $0 \leq \mu_\pi \leq 2$ and $0 \leq \mu_{y^{gap}} \leq 2$, where we solve each combination of Taylor rule coefficients for all values of $0 \leq \lambda^\pi \leq 1$ and $0 \leq \lambda^y \leq 1$ and collect the number of unstable eigenvalues. With six endogenous variables in our model,[14] a unique and stable solution exists if the number of unstable eigenvalues is exactly equal to the number of endogenous variables. With more unstable eigenvalues than endogenous variables, the system does not yield a stable solution, while with less unstable eigenvalues multiple equilibria may arise.

As shown in Figure 3.6, for all values of μ_π and $\mu_{y^{gap}}$ analyzed here, there exist combinations of inattentiveness towards output and inflation for which the model yields exactly six unstable eigenvalues, so that a unique and stable solution emerges. However, if monetary policy does not respond more than one-to-one to changes in inflation ($\mu_\pi \leq 1$), there exist also combinations of λ^π and λ^y with multiple solutions to the model system. Hence, the result that monetary policy should respect the Taylor principle remains robust when allowing for feedback from time-varying inattentiveness to the model. Nevertheless, it seems that with recursive inattentiveness restrictions for determinacy regarding the central bank's response to the output gap matter as well: Accounting for changes in λ^π and λ^y, a unique solution for all coefficients $\mu_\pi > 1$ exists only if the central bank targets the output gap with at least a coefficient of 0.5 (the baseline value of our calibration) and is never feasible if the central bank puts zero weight on the output gap.[15] This result is mostly due to the interaction between the model and the share of agents with rational inflation expectations. Interestingly, as the Taylor rule coefficient on inflation increases from 1 to 2, multiple equilibria may emerge for an increasing range of coefficients on the output gap below 0.5. It seems that the indeterminacy region increases in the form of a step function: For values of $\mu_\pi = [1.1, 1.2]$ the model generates multiple equilibria with values of $\mu_{y^{gap}} = 0$, for $\mu_\pi = [1.3, 1.4]$ multiple equilibria can be avoided when setting $\mu_{y^{gap}} > 0.1$ and so on. This suggests that as monetary policy reacts more forcefully to changes in inflation, in order to avoid multiple equilibria it should increasingly target the output gap as well.

[14] Endogenous variables include inflation, output, nominal interest rates, natural output driven by a technology shock, the output gap as the difference between output and natural output, and the change of the output gap.

[15] Note that this result depends on the range of Taylor rule coefficients on inflation tested here. If monetary policy targets inflation with a coefficient larger than 2, a coefficient on the output gap larger than 0.5 might be necessary to ensure determinacy. However, since most models assume a reaction coefficient to inflation of about 1.5 as in our calibration, we restrict the analysis to the range $0 \leq \mu_\pi \leq 2$.

3.4 Conclusion

Building on the model derived in the previous chapter 2, we present simulation results from a DSGE model with recursive inattentiveness. Extending the models of sticky information in Mankiw and Reis (2001, 2002, 2003, 2007), we endogenize the probability that agents may update to the new information set. Employing a switching mechanism from Brock and Hommes (1997), agents decide on their degree of inattentiveness towards inflation and output each period by choosing optimally between losses under forecasts with sticky information and a fixed cost of updating to the new information set. While in chapter 2 it was assumed that agents choose predictors given the model simulation, we extend this approach by allowing for recursive feedback from predictor choice to the model solution. This yields a dynamic equilibrium path with an endogenous and time-varying share of agents with rational expectations.

We find that when changes in the degree of inattentiveness influence the model solution, simulated time series for output and nominal interest rates exhibit very strong persistence with autocorrelation close to a random walk. Inflation in our model shows a persistent trend, but relatively strong short-run fluctuations. However, for reasonable cost-push shocks on inflation, the simulated series has an autocorrelation coefficient of about 0.5, close to empirical values for quarter-on-quarter inflation in the U.S. Hence, it seems that our model with recursive inattentiveness can replicate the stylized fact of strong persistence in aggregate inflation and output data as highlighted by Fuhrer and Moore (1995) without resorting to the assumption of autocorrelated shocks or lagged endogenous variables in the IS and Phillips curve.

All main results from the earlier analysis in chapter 2 remain robust also when allowing for interaction between agents' switching and the model solution. We still find that on average agents choose to pay more attention to output than to inflation. While the share of agents with rational expectations is positively correlated with the forecasted variables, the share of rational inflation expectations is also strongly correlated with the variance of interest rates, emphasizing the link between monetary policy and attentiveness towards inflation. However, with feedback from predictor choice we additionally find that also the share of agents with rational output expectations is to some degree correlated with the variance of inflation and of nominal interest rates. Agents in our model thus behave near-rationally as in Akerlof and Yellen (1985) and Akerlof et al. (2000), paying more attention to recent developments of output and inflation in times of high volatility in the economy and ignoring smaller changes. Note that in a related model with near-rational inflation expectations, Ball (2000) also finds that the model generates strong persistence in inflation.

With respect to the stylized fact of a hump-shaped response to a monetary policy shock emphasized in Christiano et al. (2005) and Rotemberg and Woodford (1997), we find that our model can reproduce a hump-shaped impulse-response of both output and inflation once the degree of inattentiveness is sufficiently high. While we find a hump-shaped response of inflation already when half the population employ the rational predictor, a hump-shaped response of output is only found when all agents use outdated information.

Finally, evaluating stability of the model we find that all variables converge to their steady states after an initial shock for a range of Taylor rule coefficients and for positive and negative shocks of varying size. We thus conclude that the potential problem of chaotic long-run dynamics with strange attractors highlighted by Brock and Hommes (1997) does not arise in our model with recursive inattentiveness, at least for reasonable shocks. Regarding conditions for determinacy of the model, accounting for agents' switching between predictors reduces the size of the determinacy region. While we still find that the Taylor principle is a necessary condition for a unique and stable solution of the model, multiple equilibria may nevertheless arise for some combinations of λ^y and λ^π if monetary policy puts too little weight on the output gap. As the Taylor rule coefficient converges towards its minimal value close to 1, smaller coefficients on the output gap become feasible as well and *vice versa*.

While a number of approaches, such as Ball (2000), De Grauwe (2008, 2010) and Lansing (2009), can generate high persistence of inflation and output in models with near-rational or heuristic expectations, our model has the advantage of nesting fully rational expectations as a special case. Hence, the model generates persistence from expectational feedback, but includes the option of full rationality. Agents will be willing to take this option if the losses from forecasting with outdated information outweigh the rationality cost.

Chapter 4

Prospect Theory and Inflation Perceptions – An Empirical Assessment*

*This chapter is based on Dräger et al. (2009).

4.1 Introduction

When assessing macroeconomic models empirically, economists mostly use actual data as published by statistical institutes for the theoretical variables in these models. However, there exists overwhelming empirical evidence that peoples' knowledge and perception of these variables deviates considerably from official statistical data and their underlying concepts, questioning the widely assumed rationality of agents in the Muth (1961) sense.[1]

The gap between actual data and individuals' perceptions raises important policy questions. This is especially true for inflation. As argued by van der Klaauw et al. (2008), among others, if individuals have biased beliefs about inflation, this can seriously undermine the central bank's credibility. Conversely, a credible monetary regime can also influence inflation perceptions, for instance by creating a focal point at the inflation target.[2] Furthermore, and relating to the concept of money illusion[3], the perception gap may lead to distortions in bargaining if individuals misperceive their actual real purchasing power. To assess the effectiveness of policy propositions suggested by macroeconomic models, it is thus necessary to understand how people form perceptions about macroeconomic variables and how these perceptions influence individual behavior.

So far, the literature on the formation of inflation perceptions has mainly focused on one stylized fact, namely the observed jump in perceptions after the Euro cash changeover in 2002, where actual inflation continued to stay on a low level. Explanations for this jump range from price intransparencies (Dziuda and Mastrobuoni, 2009), difficulties in applying the conversion rates (Ehrmann, 2006), a perceptual crisis (Eife, 2006, Eife and Coombs, 2007, Fullone et al., 2007 and Blinder and Krueger, 2004), macroeconomic illiteracy (Del Giovane et al., 2008, Cestari et al., 2008), a media bias (Lamla and Lein, 2008), and expectancy confirmation (Traut-Mattausch et al., 2004).

A number of papers furthermore analyze factors influencing perceived inflation in general. Following the deviation of perceived from actual inflation rates at the Euro cash changeover, Brachinger (2006, 2008) proposes an *Index of Perceived Inflation* (IPI) meant to capture movements in perceived inflation better than usual CPI inflation. The IPI index is constructed under the assumption that agents perceive inflation according to behavioral patterns defined in Prospect Theory by Kahneman and Tversky (1979) and

[1]See Blanchflower and Kelly (2008), Blinder and Krueger (2004), Jonung and Laidler (1988), Malgarini (2008), Curtin (2007) and van der Klaauw et al. (2008).

[2]Evidence for this channel has been found in inflation perception surveys for Sweden, see Bryan and Palmqvist (2005).

[3]See Fisher (1928) for the original contribution, and Shafir et al. (2004) and Fehr and Tyran (2007) for a Behavioral Economics perspective.

Tversky and Kahneman (1981, 1991). These include the concepts of loss aversion with respect to above-average inflation and the availability bias, whereby price changes of frequently bought goods are perceived more strongly. Evaluating this index for German data, Brachinger (2006) and Jungermann et al. (2007) claim that it represents a more adequate way of capturing inflation as perceived by individuals. However, their approach has been criticized by Hoffmann et al. (2006) for its use of arbitrary ad hoc assumptions.

A further study evaluating perceived inflation is Del Giovane et al. (2008) who design a detailed survey for Italian consumers in 2006 and investigate the answers econometrically. Especially, they find a strong impact of socioeconomic factors on inflation perceptions. This is in line with findings in Jonung (1981) who claims that inflation perceptions in Sweden differ significantly between genders. Furthermore, in a recent survey, Jonung and Conflitti (2008) report differences between age, gender, occupational and regional groups with respect to opinions of the Euro currency, which may also be reflected in inflation perceptions.

Lein and Maag (2011) analyze the formation of inflation perceptions for the EU and Sweden, using data from the Joint Harmonized EU Program of Business and Consumer Surveys and Sweden's Consumer Tendency Survey. The authors reject rationality of perceptions, since quantified inflation perceptions fail the rationality conditions of accuracy, unbiasedness and efficiency. Furthermore, they find that correlations between actual and perceived inflation are rather low and in the Euro area break down completely after the Euro cash changeover. Lein and Maag (2011) find some evidence for the importance of frequently bought goods, and for the expectancy confirmation hypothesis in the Euro area after the cash changeover. This is in line with Döhring and Mordonu (2007), who report an influence of inflation expectations on perceptions in addition to actual inflation, estimating a dynamic panel model for the countries that adopted the Euro in 2002.

This chapter adds to the literature as follows. We borrow insights from Prospect Theory by Kahneman and Tversky (1979), and test for the two theoretical hypotheses regarding the formation of inflation perceptions that underly the IPI index in Brachinger (2006, 2008). First, we examine criteria for rationality of inflation perceptions, using a methodology by Souleles (2004) to construct perception errors from the qualitative data. Second, we investigate whether individuals code price increases and decreases in a different way and with different weights, implying *loss aversion* as in Kahneman and Tversky (1979), and Tversky and Kahneman (1981, 1991). With respect to inflation, the concept of loss aversion implies that inflation rates above a 'normal' rate are perceived more strongly than inflation rates below. Third, we examine which category of products has the highest impact on perceptions compared to its estimated weight in HICP inflation, and whether these are products that are bought more frequently, thus testing for the *availability bias* put forward by Kahneman and Tversky (1973).

We use the balance statistic for inflation perceptions compiled by the European Commission in the *Joint Harmonized EU Program of Business and Consumer Surveys* as a publicly available measure for inflation perceptions. The balance statistic is a qualitative measure of individuals' judgment with regard to perceived price changes in the past 12 months, coding survey responses according to whether respondents have perceived rising, constant, or falling inflation. For reasons explained below, we do not quantify this data. Our sample covers a panel of 10 Euro area countries from 1996–2008, allowing us to investigate the formation of inflation perceptions both before and after the Euro cash changeover.

While to our knowledge this is the first approach that empirically tests for loss aversion and the availability bias regarding perceived inflation of households, a number of studies have studied Prospect Theory in models for aggregate consumption. Foellmi et al. (2011) incorporate loss aversion with respect to negative changes in consumption into a Ramsey growth model. An aggregate Euler equation with loss aversion from a similar model is estimated in Rosenblatt-Wisch (2008) for the U.S., where GMM estimates suggest a loss aversion parameter for aggregate consumption similar to the one derived experimentally in Tversky and Kahneman (1991). Recently, Gaffeo et al. (2011) analyze the transmission of monetary policy in a DSGE model with loss aversion regarding consumption. The model solution is state-dependent and the authors show that monetary policy shocks affect output more adversely during contractionary phases. This is due to an increase in the intertemporal elasticity of substitution between current and future consumption and to a lower marginal rate of substitution between consumption and leisure, affecting pass-through of interest rate shocks to prices.

Our analysis suggests the following results: First, we reject rationality of inflation perceptions, as they fail the conditions of unbiasedness and efficiency. Second, we find loss aversion with respect to inflation over the whole sample period. However, whereas the reference rate of inflation seems to have been close to average inflation before the Euro introduction, after the Euro cash changeover we find a significant increase in the reference rate. This suggests a structural break in the perception-inflation relation at the changeover, which affected the inflation rate deemed 'normal'. Third, we find that price inflation of frequently bought goods categories has a significant effect on perceived inflation in the pre-Euro sample period, while inflation rates of other price categories are not significant. For the post-Euro sample period, we find that the most frequently bought categories of goods, such as food and transport, continue to have a highly significant effect on inflation perceptions, but other, less frequently purchased, categories become significant as well. This suggests a generally increased awareness of price increases in different goods categories after the Euro introduction in our sample.

This chapter is structured as follows. Section 4.2 contains a detailed discussion of the theoretical propositions with regard to inflation perceptions. Section 4.4 proceeds with presenting the estimation design, followed by a description of the data set and its statistical properties in section 4.3. In Section 4.5, we discuss our results. Section 4.6 concludes.

4.2 Theoretical Hypotheses

In order to develop testable theoretical hypotheses about individuals' formation of inflation perceptions, we build on *Prospect Theory*, which was developed by Kahneman and Tversky (1979), and Tversky and Kahneman (1981, 1991) as an alternative decision theory under risk and uncertainty opposed to the traditional expected utility theory.[4]

The first hypothesis regards *loss aversion* (Kahneman and Tversky, 1979 and Tversky and Kahneman, 1981, 1991):

> Individuals code price changes and evaluate them against a reference price. Higher prices are perceived as losses whereas lower prices are perceived as gains. Price increases are evaluated more strongly than price decreases, the exact quantity being captured by the loss aversion parameter.[5]

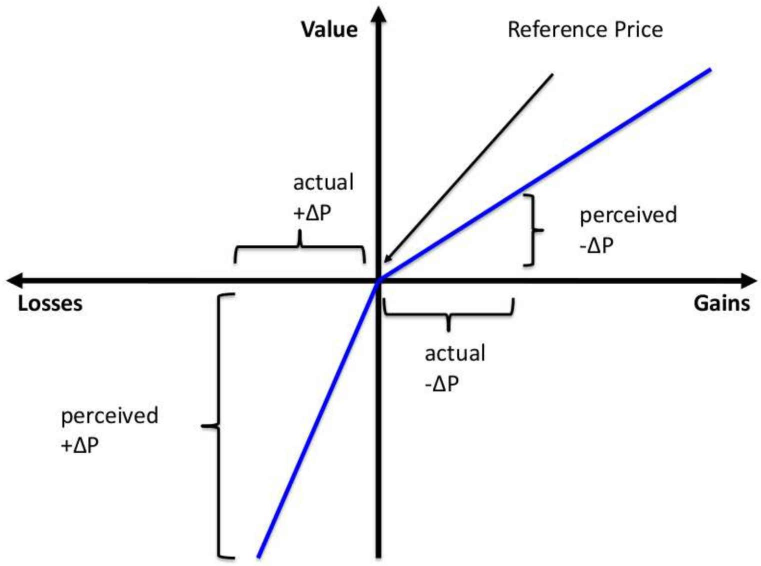
The existence of loss aversion leads to a kink in the value function at the reference point with a steeper slope in the loss region, as shown in Figure 4.1.

In order to determine the reference price, two routes can be followed. In the context of consumer choice, the reference price is given by the *fair* price, which is determined by consumers' perceptions of sellers' costs. This idea has first been proposed by Thaler (1985) as the original study relating prospect theory to consumer choice and has recently been pursued further by Rotemberg (2005, 2008). With regard to inflation perceptions, Brachinger (2006) argues that one could simply take a past price as the reference price.

[4]See Starmer (2004) for an overview of developments in decision theory under risk.

[5]Note that Prospect Theory defines loss aversion with respect to prices, while we analyze loss aversion with respect to inflation. This implies that a certain increase in prices, i.e. a certain inflation rate is deemed 'normal', while inflation rates above this 'normal' price increase are perceived as a loss. Also, analyzing loss aversion with respect to inflation entails a dynamic view of price developments, where reference prices and the reference inflation rate are grounded in households' historical experience.

Figure 4.1: Prospect Theory and Inflation Perceptions



However, it is not clear whether one should use an average price of a bundle of goods and how long the reference time period should be.

To our knowledge, Jungermann et al. (2007) and Capistrán and Timmermann (2009) present the only empirical investigation of loss aversion with respect to inflation perceptions and expectations. The former perform an experimental study, and find a loss aversion parameter of about 2. The latter assume that agents use an asymmetric loss function for evaluating their inflation forecasts. Testing this assumption empirically for the Survey of Professional Forecasters in the US, they find that 78% of the forecasters' asymmetry parameters fall between -2 and 2. This relates well to studies of loss aversion in other areas where approximately the same parameter has been found.[6]

Hoffmann et al. (2006) question the claim that price increases are judged differently from price decreases, i.e. whether individuals behave asymmetrically with respect to price changes. Whereas Hoch et al. (1994) in an experimental study for US retailers deny any asymmetry, support for loss aversion is given by Hardie et al. (1993) and Camerer (2000). However, both of the quoted studies examine consumers' purchasing

[6]See for example Tversky and Kahneman (1991), Hardie et al. (1993) and Rosenblatt-Wisch (2008).

reactions to price changes, not individuals' changes in perceptions with regard to price changes. To the best of our knowledge, the only existing study dealing with asymmetries in inflation perceptions is Del Giovane et al. (2008). They add an additional question to their survey of Italian consumers, asking respondents whether they have observed any price decrease over the last five years. They then find that those who replied with 'yes' exhibit considerably lower inflation perceptions than the remaining sample, hence providing some support for asymmetric inflation perceptions. Our analysis allows us to directly test for this hypothesis in a panel setup, evaluating if there exists a higher impact of periods with 'losses' in inflation on perceptions, and testing for differences in the relation between the pre-Euro and the post-Euro periods.

The second hypothesis regards the *availability bias* (Kahneman and Tversky, 1973 and Tversky and Kahneman, 1981):

> Individuals perceive price changes stronger the more often they buy a particular product.

According to the *Weber-Fechner Psychophysical Law*[7], inflation perceptions are a logarithmic function of actual inflation. Indeed, Tversky and Kahneman (1981) have shown in an experimental study that individuals perceive a price change of 5% to be higher for a relatively cheap good than for a relatively expensive one. This can be explained by the availability heuristic, a term coined by Kahneman and Tversky (1973), who claim that agents will assess the frequency of events by the ease with which they can be remembered. Hence, for inflation perceptions, individuals perceive price changes stronger, the more often they buy a particular product. In an experimental study for Germany, Jungermann et al. (2007) find empirical support for this hypothesis, and Del Giovane et al. (2008) point to several studies providing further evidence for single countries. Kurri (2006), for instance, analyzes correlation coefficients of inflation perceptions and price changes in product groups included in the HICP and finds some evidence for the availability bias. In contrast, Hoffmann et al. (2006) state that what matters is the impact of the price increase on the consumer's overall budget, not the frequency of the purchase. Döhring and Mordonu (2007) and Aucremanne et al. (2007) use an index of Frequently Out-Of-Pocket Purchases (FROOPP) in their panel estimations and do not find that it performs better than aggregate HICP inflation.

[7]See Thaler (1980) and Batchelor (1986).

4.3 Data Set and Statistical Properties

4.3.1 Perceived and Actual Inflation

The two hypotheses from Prospect Theory are tested empirically for a panel of 10 EMU-Countries consisting of Austria, Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Portugal, and Spain for the time period from January 1996 to November 2008. Our sample thus covers the Euro area almost completely, and the sample period is long enough to enable us to test for differences between the pre-Euro and the post-Euro periods.

We use the balance statistic of Question 5 of the *Joint Harmonized EU Program of Business and Consumer Surveys* by the European Commission as our measure of perceived inflation. The survey provides a qualitative measure from a pentachotomous survey, asking participants whether they think prices have risen a lot / risen moderately / risen slightly / stayed about the same / fallen over the last 12 months. Denoting the shares of answers in each category as s1, s2, s3, s4 and s5, the balance statistic is obtained as $s1 + 0.5s2 - 0.5s4 - s5$. While most empirical studies on perceived or expected inflation with data from the Joint Harmonized EU Program of Business and Consumer Surveys by the EC also make use of the balance statistic, there exist methods to quantify the qualitative data, most notably the probability method by Carlson and Parkin (1975) and Batchelor and Orr (1988). However, the quantification method demands a scaling series that perceptions, respectively expectations, are assumed to be based upon. Since it is usually assumed that perceptions of inflation are formed relative to actual inflation rates, the quantification method may lead to biased measures of perceived inflation if an existing bias in the relation between actual and perceived inflation is assumed away.[8] Comparing quantitative and qualitative survey answers for Swedish inflation perceptions and expectations, Maag (2009) finds that the assumptions underlying the Carlson-Parkin probability method are rejected and quantified inflation perceptions are not more accurate than those obtained from the balance statistic. Nevertheless, the author concludes that both quantified perceptions and measures obtained from the balance statistic are highly correlated with the mean of actual quantitative beliefs. Hence, it seems that not much can be gained from quantifying perceptions in terms of accuracy of the survey measures. Since for our approach we do not have to rely on exact quantitative values, we thus content ourselves with the balance statistic of inflation perceptions.

[8]See Nardo (2003) for a critical overview.

Actual inflation rates are measured with annual inflation rates of harmonized consumer price indices (HICP) from Eurostat. Additionally, in order to be able to test the availability hypothesis, we employ data on the 12 COICOP-categories, that together form the HICP, and the index of frequent out-of-pocket purchases (FROOPP) from Eurostat. The FROOPP index consists of a weighted average of goods that are purchased on a frequent basis such as food, beverages, tobacco, non-durable household goods, transport services and fuel, hotels, restaurants and hairdressing. All data are available on a monthly basis.

Comparing time series for actual HICP inflation and for perceived inflation from the balance statistics, the jump in perceptions at the Euro introduction is strikingly obvious. Actual HICP inflation rates in all the countries of our sample do not match the strong increase of perceptions at the Euro cash changeover, and in some cases even fall after the currency change (see Figure 4.2).

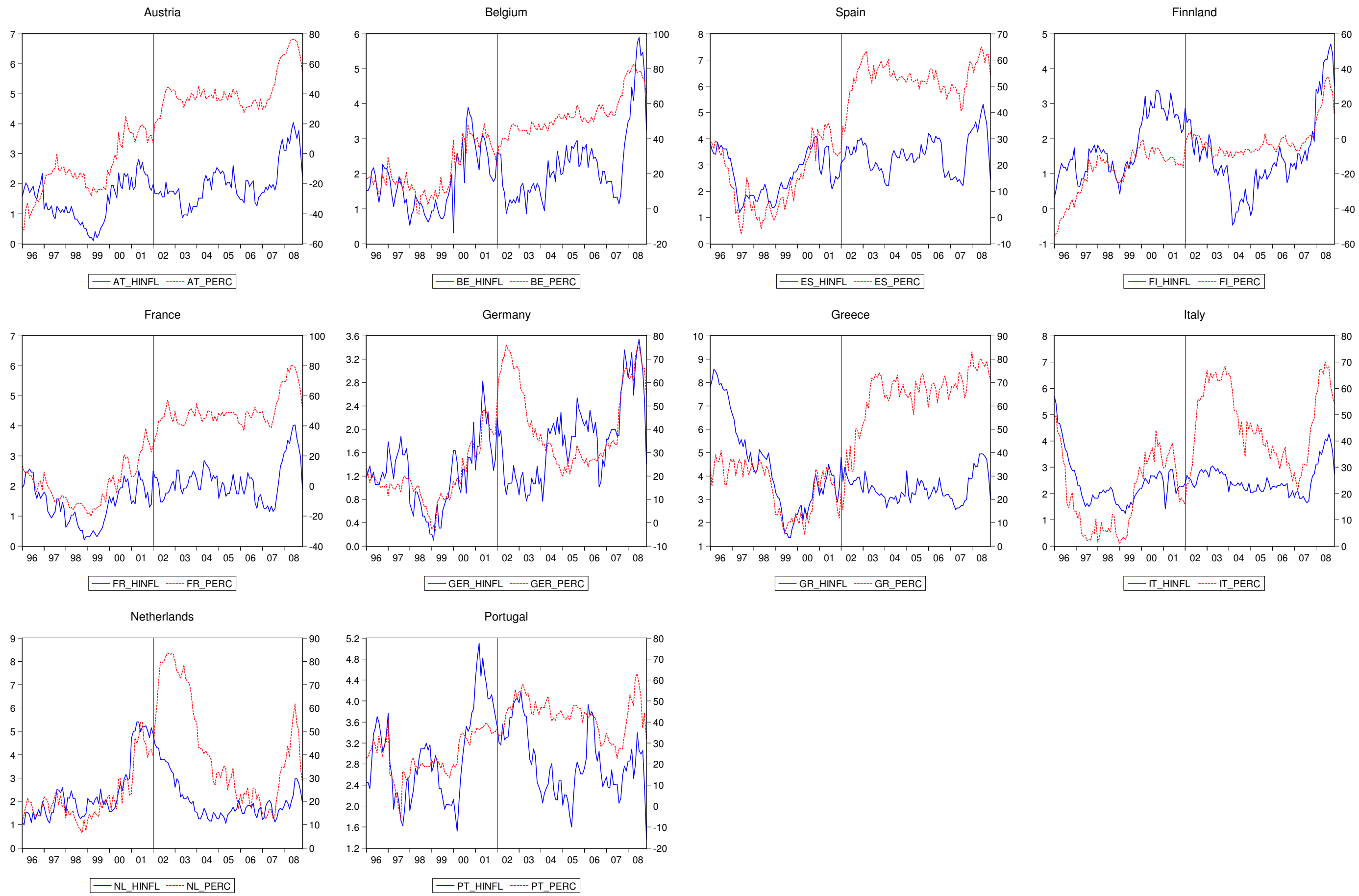
4.3.2 Unit Roots and Cointegration

We test the time series of aggregate and COICOP-inflation and of perceived inflation rates for panel unit roots in order to avoid spurious regressions. Details on the test statistics and results are given in the appendix in Chapter C. In line with results in the literature, e.g. Lein and Maag (2011), we find that the null hypothesis of a unit root in inflation is generally rejected, while perceptions seem more persistent at least in the pre-Euro period. Generally, empirical evidence on the order of integration of inflation series is mixed, Altissimo et al. (2006) conclude in a survey that empirical findings seem to lean towards stationarity of inflation. Due to the mixed results with respect to stationarity of perceived and actual inflation rates, we proceed to test for panel cointegration between perceptions and inflation.

A detailed description of the panel cointegration tests applied and of the results is given in the appendix in Chapter C. We find significant evidence for cointegration: For both the pre- and post-Euro periods nearly all tests reject the null of no cointegration at the 1% level. This, quite intuitive, result is in line with findings in Lein and Maag (2011) for a similar sample. Considering the results from both panel unit root and cointegration tests, we estimate regressions in the analysis in levels, making use of Engle and Granger's superconsistency argument.

Since much of the empirical literature on perceived inflation has found a jump in perceptions occurring shortly after the Euro cash changeover, it seems natural to test for a structural break in the relation between actual and perceived inflation in our panel.

Figure 4.2: Inflation and Perceptions for all Countries



Tables C.5 and C.6 in the appendix in Chapter C present results from a Quandt-Likelihood-Ratio test for structural breaks for each country in our sample that runs individual tests over each time period and selects the date with the maximum Wald F-Statistic as the break date. The test is estimated for our models of loss aversion and availability given above.

It clearly emerges that a structural break occurred in all models shortly after the Euro cash changeover in January 2002. This structural break is highly significant for all EMU-countries in the loss aversion models, while most countries marginally miss significance in the availability model. Overall, there is convincing evidence of a structural break at the Euro cash changeover and we divide our sample period into pre-Euro (Jan 1996–Dec 2001) and post-Euro (Jan 2002–Nov 2008) periods.

4.4 Estimation Design

Non-Rationality of Inflation Perceptions

Since we are interested in analyzing a general model of inflation perceptions, we begin by testing for alternative theories of the way agents may form inflation perceptions. Specifically, we test for rationality of inflation perceptions, and for adaptive perceptions.

Although our data for inflation perceptions are not quantified, we can nevertheless test for rationality by employing a test developed by Souleles (2004), based on the construction of discrete perception errors. First, we generate two discrete variables π_{it}^{DIS}, $perc_{it}^{DIS}$ for each country i:

$$\pi_{it}^{DIS},\, perc_{it}^{DIS} = \begin{cases} +1, \text{ if } \Delta\pi_{it},\, perc_{it} < 0 \\ 0, \text{ if } \Delta\pi_{it},\, perc_{it} = 0 \\ -1, \text{ if } \Delta\pi_{it},\, perc_{it} > 0 \end{cases}$$

Here, $perc_{it}$ stands for the so-called balance statistic of inflation perceptions which summarizes the survey asking individuals in period t how they perceive prices today compared with one year ago (see section 4.3 for more details). The balance statistic will be positive if more people think that prices have risen than fallen, and vice versa. Hence, we can construct the discrete variable $perc_{it}^{DIS}$ by exploiting the sign of the perception series. The change of the inflation rate, $\Delta\pi_{it}$, is computed as the difference between inflation in period t and in period $t-12$, to match the timing of the survey question. Country specific perception errors are then computed as $perc_{it}^{ERROR} = \pi_{it}^{DIS} - perc_{it}^{DIS}$.

Hence, given the underlying coding $\{-1, 0, 1\}$ of the inflation and perception variable, the perception error can take on the values $\{-2, -1, 0, 1, 2\}$. Since in our data set, neither the perceptions nor the inflation rate remains constant, this reduces to $\{-2, 0, 2\}$. Splitting the sample in January 2002 to account for the Euro cash changeover, we apply three standard tests of rationality (see for instance Mankiw et al., 2004, Jonung and Laidler, 1988):

Testing for a bias:

$$perc_{it}^{ERROR} = \alpha_{i0} \tag{4.1}$$

Testing for information efficiency:

$$perc_{it}^{ERROR} = \alpha_{i0} + \beta_0 perc_{it-1}^{DIS} \tag{4.2}$$

Testing for error persistence:

$$perc_{it}^{ERROR} = \alpha_{i0} + \beta_0 perc_{it-1}^{ERROR} \tag{4.3}$$

Despite the ordinal nature of the dependent variable, we can still estimate the equations by fixed effects with correlated panels corrected standard errors, interpreting the country specific constants as average perception errors.

Adaptive inflation perceptions are tested for by regressing perceptions on their own lag and on actual inflation rates. If the coefficient of the lagged dependent variable is found significantly positive and close to one, it will be interpreted as evidence of persistent, and thus adaptive, perceptions. Results are presented in Table 4.3 together with dynamic panel estimates of loss aversion.

Loss Aversion

In order to test for the existence of loss aversion with respect to rising inflation, we construct two threshold-dummies that serve to capture the periods where losses in the form of rising inflation occurred. If the hypothesis of loss aversion holds, we should find a significantly stronger impact of those ‘loss’ periods on perceived inflation than of the ‘gain’ periods in inflation. This corresponds to the finding of a kink in the perceptions-inflation relation as shown in Figure 4.1. The threshold-dummies for all $i = 1, 2, ..., 10$ countries in the panel are defined as follows:

$$\text{thold}_{1,it} = \begin{cases} 1 \text{ if } \pi_{it} > \pi_{it}^{MA} \\ 0 \text{ otherwise,} \end{cases}$$

$$\text{thold}_{2,it} = \begin{cases} 1 \text{ if } \pi_{it} > \pi_{it}^{HP} \\ 0 \text{ otherwise,} \end{cases}$$

where π_{it}^{MA} represents a five-month moving-average of inflation and π_{it}^{HP} stands for recursively HP-filtered inflation. The dummies thus take on the value of one for periods with above-average inflation, and zero otherwise. The threshold-dummies are then combined with HICP inflation rates to test for a significant difference between periods of 'losses' in inflation (i.e. above-average inflation) and periods of 'gains' in inflation (i.e. below- or average inflation):[9]

$$perc_{it} = \alpha_{i0} + \alpha_1 perc_{it-1} + \beta_1 \pi_{it} + \beta_2 (thold_{1,2it} * \pi_{it}) + \varepsilon_{it} \tag{4.4}$$

A significantly positive coefficient β_2 in equation (4.4) suggests higher perceived inflation rates in periods of rising inflation for our panel and, thus, gives evidence of loss aversion with respect to prices. Note that equation (4.4) models loss aversion with respect to inflation as a long-run phenomenon, in line with the theory in Kahneman and Tversky (1979).

Before estimating equation (4.4) with the threshold dummies defined above, we test for non-linearities in the relationship between perceived and officially reported inflation rates in order to evaluate whether the threshold-dummy approach provides an appropriate model of loss aversion in the perceptions-inflation relation. Hence, we estimate a popular model for non-linear behavior – the so-called smooth-transition autoregressive model or STAR model (van Dijk et al., 2002, Teräsvirta, 2004):

$$y_t = \phi' z_t + \theta' z_t G(\gamma, c, s_t) + \varepsilon_t \tag{4.5}$$

where $z_t = \left(w_t', x_t'\right)'$ is a vector of explanatory variables, $w_t' = (1, y_{t-1}, \ldots, y_{t-p})'$, and $x_t = (x_{1t}, \ldots, x_{kt})'$. Furthermore, ϕ and γ are parameter vectors and $\varepsilon_t \sim \text{iid}\,(0, \sigma^2)$. The transition function $G(\gamma, c, s_t)$ is a continuous function that is bounded between 0 and 1 with s_t as a transition variable, γ as a parameter governing the smoothness and c as a kind of threshold parameter. In general, it is possible to interpret such a model

[9] We tested for possible endogeneity of inflation rates in equation (4.4), but found no correlation between π_{it} and ε_{it} in any of the specifications. We also estimated equation (4.4) including the threshold dummy as both intercept and slope dummy, but found no significant results.

either as a regime-switching model with two (or more) regimes – as we do here – or as a model containing a continuum of possible regimes. Our choice for the transition function is a logistic function

$$G(\gamma, c, s_t) = \left(1 + \exp\left\{-\gamma \prod_{k=1}^{K} (s_t - c_k)\right\}\right)^{-1}, \quad \gamma > 0 \tag{4.6}$$

Under $K = 1$, this gives a so-called logistic STAR model with one threshold and two regimes (LSTAR1). Under this specification, the parameter c can be interpreted as a 50% probability threshold for being in one of the two regimes as the function changes monotonically from 0 to 1 in s_t and $G(\gamma, c, s_t) = 0.5$.

This model has only recently been extended to panel data by Gonzalez et al. (2005), however, until now, it is not sure how this framework would work for dynamic panels (see Hansen, 1999). Hence, given the persistence of inflation perceptions, we proceed with the estimation of STAR models separately for each country i. Using the logistic function (4.6) as transition function, π_t as transition variable, one lag of perceptions, and setting $K = 1$,[10] we estimate the following equation:

$$perc_{it} = \alpha_{i0} + \alpha_{i1} perc_{it-1} + \alpha_{i2}\pi_{it} + [\beta_{i0} + \beta_{i1} perc_{it-1} + \beta_{i2}\pi_{it}]\, G(\gamma, c, \pi_{it}) + \varepsilon_{it} \tag{4.7}$$

Teräsvirta (2004) suggests a modeling cycle for fitting STAR models, starting with linearity tests to check whether using a nonlinear model is necessary at all. However, these tests are expected to have low power, since we include a direct effect of the transition variable on inflation perceptions (see Fouquau et al., 2008). Moreover, Fok et al. (2005) illustrate the difficulties in estimating univariate STAR models, and recommend partial pooling to overcome these problems. These caveats have to be kept in mind when interpreting the results of the linearity tests.

Availability

The availability bias is tested in equations (4.8) and (4.9). In a preliminary analysis, we regress perceived inflation on HICP inflation and FROOPP inflation, both together in one model and separately:

[10] Only in the case of Belgium, we estimated a three-regime model ($K = 2$ = LSTAR2) since a LSTAR1 did not yield satisfactory results.

$$perc_{it} = \alpha_{i0} + \alpha_1 perc_{it-1} + \beta_1 \pi_{it} + \beta_2 \pi_{it}^{FROOPP} + \varepsilon_{it} \tag{4.8}$$

By construction, the FROOPP index reflects price changes of frequently bought goods. Setting alternatively $\beta_1 = 0$ or $\beta_2 = 0$, we can analyze information criteria and R^2 in order to infer whether the model with aggregate inflation or with FROOPP inflation is preferred when explaining perceptions.

A more detailed test of the availability bias is given in equation (4.9), where we estimate the impact of price inflation of individual COICOP-categories on perceived inflation. The twelve COICOP-categories comprise price indices for those goods categories that form the harmonized consumer price index, such as food, housing, transport, education etc. A description of the COICOP-categories is given in Table C.7 in the appendix in Chapter C.

$$perc_{it} = \alpha_{i0} + \alpha_1 perc_{it-1} + \sum_{j=1}^{12} \beta_j \pi_{j,it}^{COICOP} + \varepsilon_{it} \tag{4.9}$$

In order to evaluate the strength of the effect of COICOP-inflation rates on perceptions, we normalize the significant β_j coefficients with the standard deviations of corresponding COICOP-inflation rates:

$$\overline{\beta}_j = \frac{\beta_j * s.d.(\pi_j^{COICOP})}{\sum_{j=1}^{12} \beta_j * s.d.(\pi_j^{COICOP})}$$

The normalized coefficients are then compared to those constructed with the average weight of each COICOP-category in the HICP index over the period analyzed here:

$$\overline{weight}_j^{HICP} = \frac{weight_j^{HICP} * s.d.(\pi_j^{COICOP})}{\sum_{j=1}^{12} weight_j^{HICP} * s.d.(\pi_j^{COICOP})}$$

These normalized coefficients thus reflect the weights that individual COICOP-inflation should receive if perceptions were equal to actual inflation rates. If the availability hypothesis holds, we should find a significantly stronger effect of inflation of price categories of frequently bought goods, such as food and transport, on perceived inflation compared to actual inflation.

4.5 Results

This section presents results of our panel analysis of loss aversion and availability with respect to inflation. Due to our finding of cointegration between actual and perceived inflation, we estimate all equations in levels, using dynamic fixed effects to account for the high degree of persistence in perceived inflation. Even if this estimator suffers from the Nickell (1981) bias, this is not a severe problem since T is significantly larger than N in our sample. For the same reason, the Arellano and Bond (1991) estimator would be computationally inefficient. Hence, we employ the dynamic fixed effects estimator and check for a possible influence from the Nickell bias by using the 'Least Squares Dummy Variable Corrected' (LSDVC) estimator proposed by Bruno (2005).[11] The results are robust across all estimators. Additionally, conducting the Pesaran (2004) and the Breusch and Pagan (1980) tests of error cross-section dependence reveals that residuals are correlated across panels.[12] Hence, we present estimates with correlated panels corrected standard errors.

4.5.1 Rationality Tests

Generally, rationality is rejected if any of the coefficients in the test regressions (4.1)–(4.3) for a bias, information efficiency and error persistence is found significantly different from zero. The results in Table 4.1 suggest that all countries in our sample exhibit a significant bias in perceived inflation, with the exception of Austria and France in the pre-Euro period. Furthermore, accounting for past inflation perception significantly reduces perception errors in both sample periods, thus suggesting inefficiency. Finally, we find that perception errors are strongly persistent, which also implies a form of inefficiency. Overall, we thus reject rationality of inflation perceptions in our sample errors. This is in line with findings by Jonung and Laidler (1988) for Swedish inflation perceptions and with results in Lein and Maag (2011) for quantified inflation perceptions of a European sample.[13]

[11]Results are available from the authors upon request.

[12]Test results are available from the authors upon request.

[13]Following Souleles (2004), we repeated the estimations by including time fixed effects, and applied nonparametric rationality tests. Again, rationality is strongly rejected. Results are available upon request.

Table 4.1: Non-Rationality of Inflation Perceptions

	Bias		Efficiency		Persistence	
	1996–2001	2002–2008	1996–2001	2002–2008	1996–2001	2002–2008
$perc^{ERROR}$	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
at	-.100	1.133***	.0416	.684***	-.0127	.430***
	(.128)	(.109)	(.121)	(.162)	(.110)	(.0898)
be	.933***	.892***	.573***	.443***	.348***	.324***
	(.129)	(.109)	(.154)	(.162)	(.114)	(.0851)
es	.633***	.867***	.363**	.419***	.210**	.329***
	(.153)	(.109)	(.155)	(.162)	(.118)	(.0825)
fi	-1.100***	-.386***	-.714***	-.218**	-.351***	-.146
	(.128)	(.120)	(.155)	(.120)	(.110)	(.0972)
fr	.100	.867***	.151	.419***	.0233	.329***
	(.128)	(.109)	(.119)	(.162)	(.105)	(.102)
ger	.700***	.964***	.352**	.515***	.267***	.366***
	(.123)	(.110)	(.148)	(.163)	(.0967)	(.0958)
gr	1.400***	1.108***	1.014***	.660***	.478***	.421***
	(.118)	(.109)	(.147)	(.162)	(.0865)	(.0973)
it	1.167***	1.012***	.781***	.563***	.396***	.369***
	(.127)	(.110)	(.155)	(.163)	(.0915)	(.0908)
nl	.633***	1.253***	.247**	.804***	.221**	.476***
	(.120)	(.106)	(.149)	(.160)	(.107)	(.0910)
pt	.767***	1.181***	.406***	.732***	.290***	.448***
	(.126)	(.108)	(.152)	(.161)	(.0896)	(.0862)
$l.perc^{DIS}$	-	-	-.386***	-.449***	-	-
			(.0876)	(.120)		
$l.perc^{ERROR}$	-	-	-	-	.656***	.620***
					(.0378)	(.0321)
R^2	0.425	0.496	0.449	0.505	0.668	0.690

Note: Correlated panels corrected standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

4.5.2 Loss Aversion

Country-by-Country Smooth Transition Autoregressive Estimations

To start our empirical investigation of loss aversion with respect to inflation, we run country-by-country regressions to analyze the type of non-linearity in the relationship between perceived and actual inflation. The estimated STAR models enable us to provide evidence first for the use of dummy variables in the panel estimations of equation (4.4) and second for the threshold value that should be used in constructing the dummy.

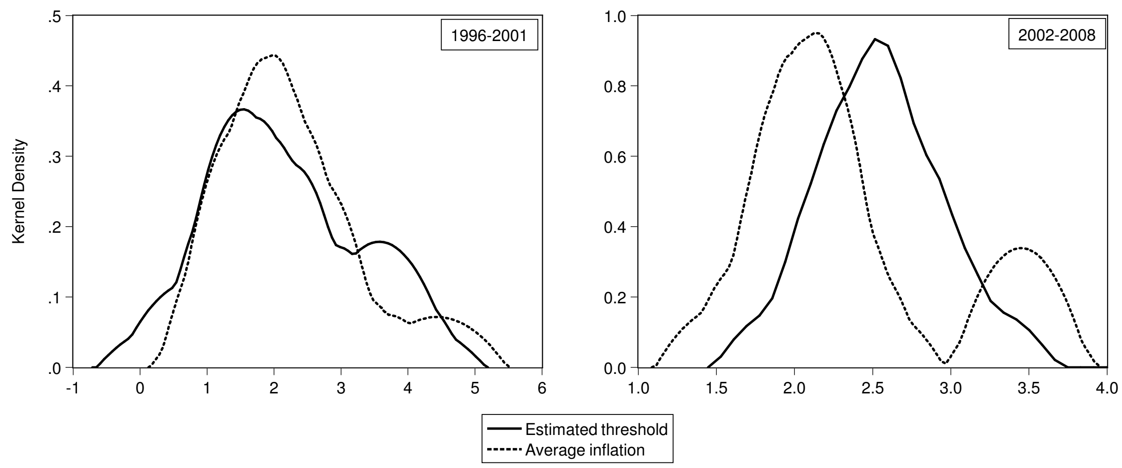
We start the analysis with tests for non-linearity. As expected, due to the low power of the individual country test, linearity can be rejected on the individual countries' level only in a few cases. On the contrary, applying the panel version of the test while ignoring possible interference through neglecting the persistence of inflation perceptions, leads to a strong rejection of linearity.[14] Hence, we take this as suggestive evidence to proceed with the estimation of LSTAR1 models for each country.

Table 4.2: Country-by-Country LSTAR Estimates

	1996–2001			2002–2008		
	Uncond. Mean	C_1	γ	Uncond. Mean	C_1	γ
at	1.42	2.03	17.70	2.03	2.60	303.37
be	1.74	0.54	31.20	2.30	2.81	4018.80
es	2.63	3.98	184.74	3.40	2.37	53.79
fi	1.76	1.05	16.11	1.55	9.10	2.46
fr	1.37	1.74	259.65	2.16	2.26	40.54
ger	1.21	1.75	15.44	1.85	2.57	19.40
gr	4.43	3.51	4.30	3.50	3.23	594.75
it	2.40	3.23	74.54	2.52	2.78	5.04
nl	2.42	1.97	7218.24	2.07	2.36	404.47
pt	2.96	1.68	1011.52	2.03	1.94	18.19
average	2.23	2.15	883.34	2.34	3.20	546.08
median	2.08	1.86	52.87	2.12	2.59	47.17

[14]Results are available upon request.

Figure 4.3: Estimated Thresholds and Average Inflation



After estimating the initial parameters by a grid search, as proposed in Teräsvirta (2004), we estimate the respective model for each country and for the pre- and post-Euro periods. Table 4.2 gives a summary of the main relevant parameters, namely the smoothness parameter γ and the threshold C_1 together with the mean of inflation rates over the two sample periods. Figure 4.3 furthermore shows the Kernel density of average inflation over the EMU sample and the estimated thresholds for the pre- and post-Euro periods, respectively.

Four points are worthwhile mentioning here: First of all, in almost all cases, there is evidence of a very steep transition function, i.e. γ is quite large and the crossplots show sudden jumps between regimes rather than a smooth change.[15] Second, on average over all countries in the pre-Euro period, the thresholds C_1 do not differ much from the historical averages of inflation rates as the respective column in Table 4.2 and Figure 4.3 indicate. Therefore, a mean or a mean with some time variation seems to be not a bad choice for a threshold between regimes of 'gains' and 'losses' in perceived inflation. However, regarding the post-Euro period, we estimate a mean threshold C_1 about 1 percentage point above average inflation over the sample, and about 0.5 percentage points higher in the median. This suggests that the reference rate of inflation increased after the Euro cash changeover, which might be related to the strong increase in perceived inflation. Finally, we find that for those countries where inflation fell radically over the

[15]Crossplots of the transition function of the LSTAR regressions are available from the authors upon request.

course of the estimation sample (Spain, Greece, Portugal), the estimated threshold is lower than the reported inflation rate. This could indicate that for a certain period households regarded or perceived actual inflation as 'too high' relative to levels which are regarded as 'normal levels' or 'fair levels' of inflation.

Overall, estimations of LSTAR models of equation (4.4) thus support the use of threshold dummies to distinguish between periods of 'losses' and periods of 'gains' in perceived inflation. The change between the two regimes resembles a jump more than a smooth transition, and can thus be captured via threshold dummies. In the following, we thus proceed to estimate panel models of equation (4.4) with threshold dummies as specified in section 4.4.

Panel Estimations of Loss Aversion

Next, we present results of the panel estimation of loss aversion as in equation (4.4) with both threshold dummies in Table 4.3, where the first column additionally reports the test for adaptive perceptions.[16]

For both estimation periods, we find that lagged inflation perceptions yields a highly significant coefficient close to 0.9 in the preliminary regression without threshold dummies, while actual inflation rates are also highly significant with a coefficient of about 1.38. This suggests indeed a high degree of persistence in inflation perceptions; a results which was also implied by the panel unit root tests above. We thus cannot rule out that inflation perceptions in our panel are to some degree formed adaptively.

Regarding estimations of loss aversion in the pre-Euro estimation period, both threshold models yield highly significant results, and give evidence of loss aversion with respect to prices: Coefficients on $thold_{1,2it} * \pi_{it}$ are significantly positive for both threshold1 and threshold2, with slightly higher coefficients for the latter threshold. Hence, perceived inflation is found to be significantly higher for those periods where inflation was above average, i.e. losses in inflation occurred. A Pesaran (2007) CADF test for a panel unit root in the residuals shows no indication of misspecification. Comparing the model with loss aversion to the simple model including only adaptive perceptions, we find that including the threshold dummies improves the model in terms of both the Akaike (AIC) and the Bayes Information criterion (BIC), which are lower for both threshold models.

[16] We additionally estimated equation (4.4) with the threshold dummies included as both intercept and slope dummies. However, results were not significant, so that equation (4.4) is preferred in a general-to-specific estimation strategy. Estimation results are available from the authors upon request. We thus conclude that the exact location of the kink in perception cannot be meaningfully estimated as a panel-wide average, but instead might be included in the country-specific fixed effects.

Table 4.3: Loss Aversion with Respect to Inflation

	1996–2001			2002–2008		
perc	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
l.perc	.8594***	.8678***	.8264***	.8967***	.8977***	.8968***
	(.0225)	(.0220)	(.0250)	(.0157)	(.0157)	(.0160)
π	1.3823***	.9278***	1.3954***	1.3829***	1.2854***	1.3773***
	(.2519)	(.2703)	(.2987)	(.2487)	(.2865)	(.3074)
$\pi *$ thold1	-	.4667***	-	-	.0833	-
		(.1431)			(.1325)	
$\pi *$ thold2	-	-	.6973***	-	-	.0036
			(.1664)			(.1498)
R^2	0.949	0.9574	0.944	0.965	0.965	0.965
AIC	4131.547	4121.279	3707.05	4591.998	4593.468	4593.997
BIC	4140.678	4134.975	3720.434	4601.417	4607.596	4608.125
CADF resid.	-3.941	-4.027	-3.497	-4.291	-4.318	-4.292
prob.	0.000	0.000	0.000	0.000	0.000	0.000

Note: Correlated panels corrected standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

It thus seems that while perceptions undoubtedly have a persistent element, additionally modeling the concept of loss aversion significantly improves our model of perception formation.

For the post-Euro estimation period, coefficients on the lagged dependent variable and the inflation rate are approximately comparable to those from the models over the pre-Euro sample period, but all coefficients on $thold_{1,2it} * \pi_{it}$ are now found to be insignificant. Again, test statistics suggest that all models are well specified. Our result for the post-Euro period implies that the loss aversion relationship with respect to price changes was disturbed after the introduction of the Euro, so that we no longer find a significant difference between effects of 'loss' and 'gain' periods of inflation on perceptions. Consequently, the models including the threshold dummies do not yield any improvement in terms of the AIC and BIC criteria compared to the simple model of adaptive perceptions.

This result is at odds with the assumption of loss aversion employed in Brachinger (2006, 2008)'s *IPI* index that is constructed specifically to depict inflation perceptions after the Euro introduction. Our finding could have various interpretations: On the one hand, the asymmetry in the perception of 'losses' and 'gains' in inflation as visualized by the kink of the perceptions function at the reference point could have broken down after the Euro introduction. On the other hand, our finding could be due to confusion regarding the reference point after the Euro introduction, so that 'losses' and 'gains' in inflation could no longer be distinguished clearly. This argument relates to Ehrmann (2006), who states that the increase in perceived inflation after the Euro cash changeover might have been due to complex conversion rates that introduced an upwards bias in perceptions caused by rounding errors.

In order to test the hypothesis of a change in the reference rate of inflation after the Euro introduction, recall that the LSTAR estimates suggested an increase in the threshold, i.e. the reference rate of inflation, after the Euro introduction by about 1 percentage point on average and 0.5 percentage points in the median. Note that although actual inflation rates in the Euro area did not increase after the Euro introduction, an increase in the reference rate of inflation is nevertheless plausible considering the widely held belief in the general public that prices rose substantially after the cash changeover. We thus construct adjusted threshold dummies $thold1a$ and $thold2a$ for the post-Euro period that were defined to take on the value of 1 in periods, where inflation was higher than moving-average or HP-filtered inflation plus 0.5 percentage points, and zero otherwise.[17] Panel estimations of loss aversion with respect to this higher threshold are presented for the post-Euro period in Table 4.4.

Table 4.4: Loss Aversion with Increased Reference Rate of Inflation, 2002–2008

	Dynamic Fixed Effects		LSDVC estimator	
perc	Coeff.	Coeff.	Coeff.	Coeff.
l.perc	.8974***	.8957***	.9125***	.9107***
	(.0156)	(.0157)	(.0144)	(.0143)
π	1.1932***	1.0951***	1.1074***	1.0221***
	(.2537)	(.2879)	(.2386)	(.2630)
$\pi *$ thold1a	.4258**	-	.4387**	-
	(.1810)		(.1784)	
$\pi *$ thold2a	-	.2526	-	.2499*
		(.1644)		(.1336)
R^2	0.965	0.965		
AIC	4587.371	4590.674		
BIC	4601.499	4604.802		
CADF resid.	-4.357	-4.281		
prob.	0.000	0.000		

Note: Correlated panels corrected standard errors and bootstrapped standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

With the increased reference rate of inflation, we now find that perceived inflation reacts significantly stronger to inflation in periods with actual inflation above the (increased) threshold compared to the overall effect. Hence, there is evidence of loss aversion with respect to inflation also after the Euro introduction, once the increase in the reference rate of inflation is accounted for. The model of loss aversion with increased reference rate is also preferred to the simple model of adaptive perceptions when comparing the AIC and BIC criteria. With correlated panels corrected standard errors the β_2 coefficient is significant only with the first threshold, however, the LSDVC estimates presented in Table 4.4 find significant coefficients for all models.

Our analysis thus suggests that loss aversion is indeed a persistent long-run phenomenon affecting inflation perceptions, which nevertheless changed its structure with

[17] We also tested threshold dummies defined over average inflation plus 1 percentage points, but found that for most countries inflation was above this threshold for only very few periods, rendering any statistical difference between the regimes implausible.

the Euro introduction. In that sense our results still question Brachinger (2006, 2008)'s assumptions used for the *IPI* index, who did not account for an increase in the reference point. Our findings could be related to studies by Malmendier and Nagel (2009, 2011) who find that individuals' reference point with respect to inflation expectations depends on their lifetime experience of inflation: Individuals who experienced periods of high actual inflation rates seem to have lower inflation expectations in recent years than younger individuals who are accustomed to moderate inflation rates. Similarly, the combination of moderate inflation rates and an upwards bias in perceptions at the changeover due to communication errors by the authorities, confusion with respect to conversion rates and media effects could have shifted the reference point upwards.

4.5.3 Availability

Panel Estimations of Availability of FROOPP-Inflation

The availability hypthesis is first tested by estimating coefficients of aggregate and FROOPP inflation on perceived inflation and testing for the restrictions $\beta_1 = 0$ and $\beta_2 = 0$ in equation (4.8).

Table 4.5: Availability of HICP vs. FROOPP Inflation, 1996–2001

perc	(1)	(2)	(3)
l.perc	.8370***	.8594***	.8366***
	(.0222)	(.0225)	(.0221)
π	-.1033	1.3823***	-
	(.4157)	(.2519)	
π^{FROOPP}	1.6584***	-	1.5790***
	(.3947)		(.2157)
R^2	0.951	0.949	0.951
AIC	4052.330	4131.547	4050.401
BIC	4065.979	4140.678	4059.501
LR test	-	17.590	4.730
prob.		0.000	0.030
CADF resid.	-6.287	-3.941	-6.333
prob.	0.000	0.000	0.000

Note: Correlated panels corrected standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

Table 4.6: Availability of HICP vs. FROOPP Inflation, 2002–2008

perc	(1)	(2)	(3)
l.perc	.9182***	.8967***	.9229***
	(.0153)	(.0157)	(.0151)
π	.8583*	1.3829***	-
	(.4661)	(.2487)	
π^{FROOPP}	.6541*	-	1.1227***
	(.3477)		(.2055)
R^2	0.967	0.965	0.967
AIC	3894.442	4591.998	3896.325
BIC	3908.138	4601.417	3905.455
LR test	-	5.000	3.880
prob.		0.025	0.049
CADF resid.	-4.125	-4.291	-4.112
prob.	0.000	0.000	0.000

Note: Correlated panels corrected standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

Table 4.5 presents estimates of dynamic fixed effects models of (4.8) in the pre-Euro period. Including both aggregate and FROOPP inflation in the model, we find that only FROOPP inflation yields a significant coefficient not statistically different from one, while the coefficient on aggregate inflation is found to be insignificant. Even if this finding might be due to the high multicollinearity between the explanatory variables, looking at the two submodels highlights the dominance of the FROOPP over the HICP: Restricting the coefficient of FROOPP inflation $\beta_2 = 0$, the second model yields a highly significant coefficient for aggregate inflation. Nevertheless, the likelihood ratio test rejects the restriction at the 1% level. Conversely, restricting the coefficient of aggregate inflation $\beta_1 = 0$ in the third model, we again find a highly significant coefficient on FROOPP inflation not statistically different from that in the encompassing model. While the likelihood ratio test again rejects the restriction, it can now only reject at the 5% level. Furthermore, we find lower Akaike (AIC) and Bayes Information Criteria (BIC). From a general-to-specific perspective, this implies that the FROOPP model is preferred to the model with aggregate inflation for the pre-Euro period.

Estimates for the post-Euro period are given in Table 4.6. In contrast to results for the pre-Euro period, in the unrestricted model of equation (4.8) for the post-Euro period, both aggregate and FROOPP inflation have a significant coefficient of similar magnitude. Nevertheless, the likelihood ratio test rejects the restriction $\beta_2 = 0$ at the 1% or 5% level, while the restriction $\beta_1 = 0$ can be rejected only at the 10% or 5% level. Hence, the model without aggregate inflation is preferred by the likelihood ratio test, also when comparing the information criteria. Although the encompassing model suggests a role for both aggregate and FROOPP inflation with respect to perceptions after the Euro introduction, availability of FROOPP inflation nevertheless seems to dominate over aggregate inflation.

Panel Estimations of Availability of COICOP-Inflation

Table 4.7 gives results of the dynamic panel estimations of equation (4.9), testing the availability hypothesis with respect to price changes in COICOP-categories. We define those COICOP-categories as categories of frequently bought goods which include a high percentage of goods that feature in Eurostat's FROOPP index (close to, or above, 50%). These are food & drinks (100%), alcohol & tobacco (100%), transport (42.7%), recreation and culture (50.5%) as well as restaurants & hotels (82.7%) (see Table C.7 in the appendix in Chapter C). Although only a small percentage of goods in the clothing & shoes category is included in the FROOPP index, we consider this category also to be one of frequent and direct purchases.

Overall, results in the pre-Euro period provide suggestive evidence in favor of the availability hypothesis: We find significant coefficients for inflation of those COICOP-price categories that relate to frequently bought goods, such as food & drinks, clothing & shoes, transport, recreation & culture as well as restaurants and hotels. However, the negative coefficient on price changes in the recreation & culture category is not plausible and not robust to alternative standard error specifications. While we do not find a significant effect of price changes in alcohol & tobacco on perceptions, contrary to Brachinger (2006, 2008) inflation of housing prices is found to significantly affect perceptions. Although there is a certain overlap between categories, such as prices for alcohol and prices in restaurants, the tendency emerges nevertheless that prices of those categories that are purchased on a frequent basis exert more influence over perceived inflation.

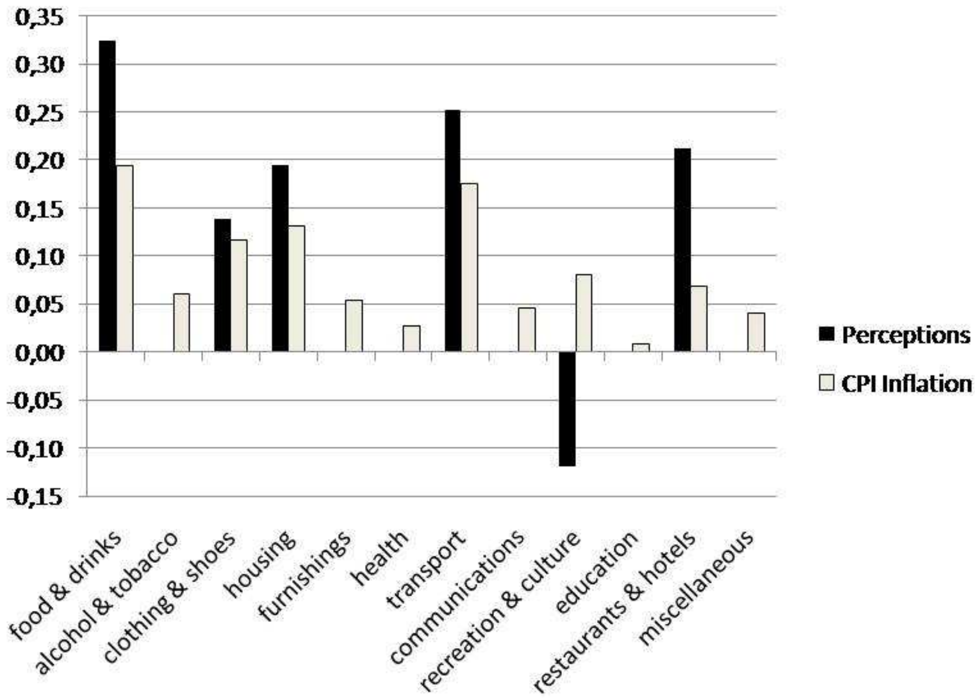
Regarding estimation results for the post-Euro period in Table 4.6, the following results emerge: Similar to our findings with respect to loss aversion, the availability of price categories regarding perceptions also seems to have shifted after the Euro cash changeover. The most important frequently bought price categories from the pre-Euro

Table 4.7: Availability of COICOP-Categories

perc	1996–2001 Coeff.	2002–2008 Coeff.
l.perc	.7281***	.8662***
	(.0275)	(.0154)
food & drinks	.8899***	.2821***
	(.1318)	(.0992)
alcohol & tobacco	.0006	-.0165
	(.0818)	(.0407)
clothing & shoes	.2856***	.0074
	(.1023)	(.0916)
housing	.5924***	-.1373*
	(.1489)	(.0784)
furnishings	-.3744	.9842***
	(.2906)	(.2741)
health	-.0193	.0508
	(.0539)	(.0530)
transport	.6125***	.4247***
	(.1285)	(.0896)
communications	.0464	.1116***
	(.0574)	(.0428)
recreation & culture	-.3859***	.3701***
	(.1453)	(.1174)
education	.0456	.0711**
	(.0723)	(.0303)
restaurants & hotels	.8344***	.0904
	(.2526)	(.1499)
miscellaneous	.3949	-.0193
	(.2544)	(.2395)
R^2	0.954	0.968
CADF resid.	-1.673	-4.129
prob.	0.047	0.000

Note: Correlated panels corrected standard errors in parentheses.
***, **, * denote significance at the 1%, 5% and 10% level, respectively.

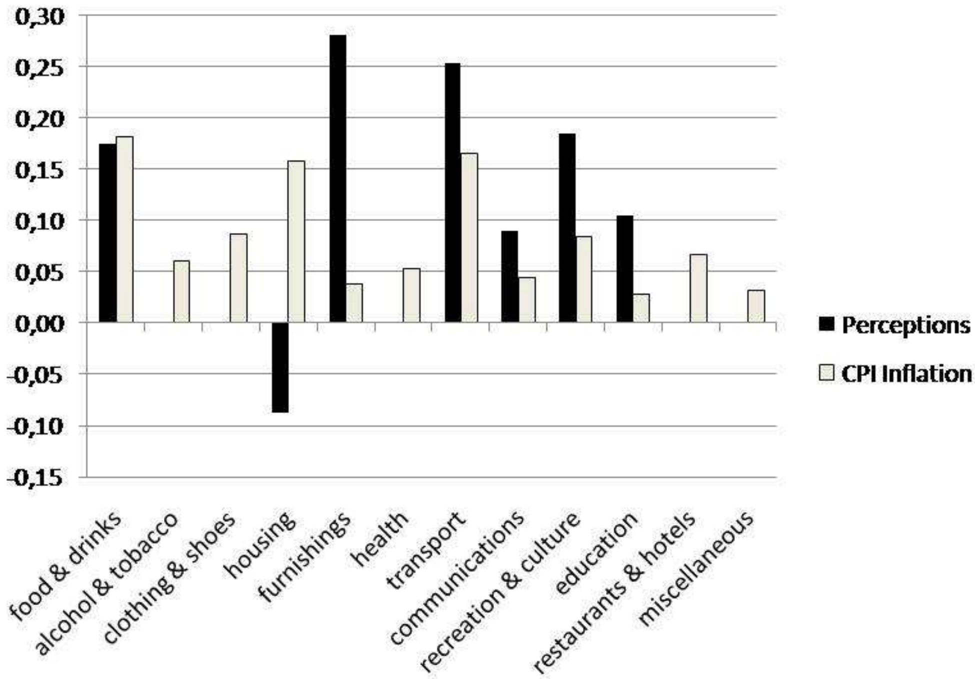
Figure 4.4: Normalized Coefficients on Perceptions and Inflation, Pre-Euro 1996–2001



estimations, namely food and transport, remain highly significant also in the post-Euro sample, suggesting that availability of these price changes still significantly influences inflation perceptions. Furthermore, price changes in recreation & culture remain significant and coefficients are now correctly signed. Yet price changes of clothing and, surprisingly, also restaurant and hotels[18], are no longer found to be significant in the post-Euro sample models, and housing prices now have a negative coefficient. Moreover, we find significant effects of price changes in furnishings, communications, as well as education on perceptions after the Euro introduction. Overall, it seems that availability of price categories with regard to perceptions generally increased after the Euro cash changeover, but the pattern of higher availability of frequently bought goods to some extent broke down. Furthermore, the persistence of the perception series – as measured by the first lag – is stronger. This points to the fact, that perception in itself is more persistent and shocks die out more slowly than before the Euro introduction.

[18]This is a surprising result, since restaurant prices were among the few prices that increased markedly after the Euro cash changeover. However, in most European countries the price hike was only temporary and did not lead to a prolonged increase in price inflation of restaurant prices. Also, there might have been a bias in perceptions introduced by the media who discussed rising restaurant prices extensively. This remains an important issue for further research.

Figure 4.5: Normalized Coefficients on Perceptions and Inflation, Post-Euro 2002–2008



Further evidence of the availability bias is given by the normalized coefficients of perceived and actual inflation to price changes in COICOP-categories. Figure 4.4 presents the result in the pre-Euro period and Figure 4.5 shows normalized coefficients for the post-Euro period.

Although of course all COICOP-categories receive a positive weight in the HICP index, perceptions seem only to react to a number of categories. The largest effect on perceived inflation in the pre-Euro period seems to come from food and transport prices, with normalized coefficients of perceptions markedly stronger compared to those on actual inflation. But also housing and restaurant prices are found to affect inflation perceptions significantly more than actual inflation in the pre-Euro sample.

Comparing the results of HICP inflation between the pre- and post-Euro periods, the weights of individual COICOP-categories remain similar with only minor changes. By contrast, the normalized coefficients of perceived inflation show quite a different pattern after the Euro cash changeover: Changes in food and transport prices still have large impacts on perceptions in the EU-sample, while food price changes seem to affect perceptions less than actual inflation. Furthermore, price changes in recreation and culture now show significantly stronger impulses on perceptions than on inflation. However, also non-frequently bought goods categories are found to have a strong influence on perceptions in the post-Euro period: Price changes in furnishings, communications as well as education all affect perceptions stronger than their corresponding HICP-weights.

4.6 Conclusion

This chapter investigates whether insights from Prospect Theory can be meaningfully applied to provide explanations for individuals' formation of inflation perceptions. Using a dynamic panel model for 10 European countries, we find some empirical support for the two theoretical hypotheses of loss aversion and the availability bias:

First, testing for alternative theories of inflation perception formation, we reject rationality of perceptions, but cannot rule out a high degree of persistence, and hence adaptive, perceptions. Our result regarding non-rationality of perceived inflation is in line with other findings in the literature, e.g. Jonung and Laidler (1988) and Lein and Maag (2011).

Second, there is evidence of loss aversion of households with respect to rising inflation for the whole panel in the pre-Euro sample period. However, there is no indication of loss aversion after the Euro cash changeover in any of the models with the same reference point. This suggests a structural break in the perception-inflation relation, where the break-down of loss aversion might be due to confusion regarding the reference price in the new currency. Testing this hypothesis, we find that the reference rate of inflation has indeed increased after the Euro cash changeover and loss aversion can be found with respect to this new reference rate. The increase in the reference rate of inflation might be due to the widely held belief that inflation rose substantially after the Euro cash changeover, contrary to evidence from actual inflation rates. Thus, although we find a change in the reference point, our estimation results nevertheless suggest that some form of loss aversion regarding inflation exists as a long-run phenomenon. This is in line with other studies reporting evidence of loss aversion in aggregate data, see for instance Rosenblatt-Wisch (2008).

Third, we find that price inflation of frequently bought goods categories has a significant effect on perceived inflation in the pre-Euro sample period, while inflation rates of other price categories are not found to be significant (with the exception of housing prices). Moreover, the normalized coefficients of those significant goods categories are much higher for perceptions than equivalent coefficients constructed from HICP weights. For the post-Euro sample period, the most important frequently bought categories of goods, such as food and transport, again have a highly significant effect on inflation perceptions, but other, less frequently purchased, categories become significant as well. This suggests a generally increased awareness of rising inflation after the Euro introduction in our sample. Similarly, Kurri (2006) studies the perception of prices from goods categories in Finland and finds that the availability bias can only explain part of the jump in perceived inflation after the Euro changeover. We thus interpret our results as tentative evidence of the availability hypothesis, since a more detailed test would only be possible with more disaggregated price data. Nevertheless, our results remain robust when we test with an index of frequently out-of-pocket purchases (FROOPP) instead of individual COICOP-prices.

Several areas of future research seem to be worth following up. First, note that it will be interesting to explain why the reference rate of inflation increased after the Euro introduction and whether this change will turn out to be stable in the future. If this were the case, it might have important implications for agents' spending behavior and inflation expectations. Second, the effect of media reports on inflation in explaining perceptions ('Agenda setting') should be analyzed especially with regard to explaining the mixed results regarding loss aversion and availability after the Euro introduction. Third, the role of inflation expectations in explaining the relation between actual and perceived inflation rates should be explored further. We analyze the interrelation between actual, perceived and expected inflation as well as the role of the media for the case of Sweden in the following chapter 5.

Chapter 5

Inflation Perceptions and Expectations in Sweden – Are Media Reports the ‘Missing Link’?*

*This chapter is based on Dräger (2011b).

5.1 Introduction

Ever since the rational expectations revolution in macroeconomics (Muth, 1961, Lucas, 1972, 1973, 1976), policy makers have emphasized the importance of inflation expectations for monetary policy making. As a consequence, a large literature on the formation of inflation expectations has emerged and many economies have introduced implicit or explicit inflation targets in an attempt to anchor expectations around the target. Analyzing survey data of inflation expectations in Sweden and the US, Bryan and Palmqvist (2005) find indeed that the introduction of the inflation target in Sweden introduced a new focal point for expectations around the target, while a similar focal point does not exist for the US. Nevertheless, a number of studies reject rationality of inflation expectations, where forecasts fail either the condition of unbiasedness or of efficiency, or both.[1]

The analysis of inflation perceptions has received less attention in the literature, but more recently the large gap between actual and perceived inflation rates occurring in most Euro countries after the cash changeover has triggered a large literature.[2] Regarding the formation of inflation perceptions in general, Jonung and Laidler (1988) as well as Lein and Maag (2011) reject rationality of inflation perceptions for a panel of European countries. In the previous chapter 4, we find evidence of loss aversion with respect to rising inflation and higher availability of price changes in frequently bought goods both before and after the Euro introduction. This result implies that certain behavioral mechanisms might influence the formation of inflation perceptions, hence also questioning the concept of rationality.

While most theoretical models assume that agents form expectations based on observed actual inflation rates, the empirical observation of potentially large deviations between actual and perceived inflation raises the question of the relationship between expected and perceived inflation. The role they play in their respective formation process then becomes an important issue for policy makers and theoretical economists alike.

[1]Studies that reject rationality of expectations include, *inter alia*, Batchelor and Dua (1987), Thomas (1999), Forsells and Kenny (2002), Mankiw et al. (2004), Dias et al. (2010) and Souleles (2004), where the latter uses micro survey data instead of aggregates.

[2]Explanations of the jump in perceptions range from price intransparencies (Dziuda and Mastrobuoni, 2009), difficulties in applying the conversion rates (Ehrmann, 2006), a perceptual crisis (Eife, 2006, Eife and Coombs, 2007, Fullone et al., 2007 and Blinder and Krueger, 2004), macroeconomic illiteracy (Del Giovane et al., 2008, Cestari et al., 2008), a media bias (Lamla and Lein, 2008) to behavioural biases such as expectancy confirmation (Traut-Mattausch et al., 2004) and loss aversion (Brachinger, 2006, 2008).

However, surprisingly little research has taken place regarding the nature of the relationship between expectations and perceptions on inflation. An early contribution, Jonung (1981) reports a significantly positive correlation coefficient between perceived and expected inflation of about 0.5, using an older version of the Swedish Consumer Tendency Survey. A similar result is also reported by van der Klaauw et al. (2008) for the US.

With regard to the direction of causality, a number of studies suggest that households often form inflation expectations based on their perception of past inflation. Analyzing qualitative responses of the February 2008 issue of the Bank of England/GfK NOP Inflation Attitudes Survey, Benford and Driver (2008) report that almost 50% of respondents stated that inflation perceptions both over the past six months and over the past year and longer were 'very important' when forming expectations. More recently, Maag (2010b) finds in a Gaussian mixture model using micro data from the Swedish Consumer Tendency Survey that about 51% of households form static inflation expectations on the basis of perceived inflation, while only 19% form forward-looking expectations based on actual inflation. Further evidence of inflation perceptions feeding into expectations is presented by Blanchflower and Kelly (2008) who report that groups with biased perceptions also form biased expectations.

However, there exists also empirical evidence of causality running from inflation expectations to perceptions: Traut-Mattausch et al. (2004) conduct experiments with restaurant menus denoted in Euro and in D-Mark and find that in all studies price trend perceptions are significantly biased towards price increases. This bias is not due to memory biases or inaccurate recall, but persists even when the original prices in the past are provided. The authors therefore attribute their finding to selective outcome correction resulting in the so-called 'expectancy confirmation hypothesis': Agents that expect prices to rise, will also perceive the price increases since calculation errors are more thoroughly corrected when they disconfirm the initial expectations than otherwise. This finding thus points to a possible direction of causality from expectations to perceptions. Evidence in line with expectancy confirmation in the context of inflation is also provided by Fluch and Stix (2005), Koskimäki (2005) and Hofmann et al. (2007).

These empirical results are integrated into a conceptual framework in Ranyard et al. (2008), specifying the relationship between individuals and their socio-economic environment. The authors hypothesize that inflation perceptions are influenced by the direct experience of price changes and also by social amplification via the media or word of mouth. Via agents' spending behavior, inflation perceptions then feed back into actual and expected inflation rates. Inflation expectations, on the other hand, are based on inflation perceptions and economic forecasts and may also be influenced by social amplification. Finally, expectations feed back into actual inflation through saving, spending and investment decisions.

In line with the importance of social amplification in the Ranyard et al. (2008) model, in his epidemiology model Carroll (2001, 2003) proposes the media to be the most important source of information about inflation developments, linking the intensity of news reporting to the share of agents using the most recent information set in a sticky-information setting à la Mankiw and Reis (2002, 2003, 2006, 2007). This line of reasoning is related to the agenda-setting literature developed in media studies by McCombs (2004) and to the rational inattention literature founded by Sims (2003), who highlights the importance of the media in providing information coding services. The empirical importance of media reports both as a transmission mechanism of information and as a possible cause for a bias in expectations and perceptions is also highlighted by Lamla and Lein (2008, 2010). Especially with regard to inflation expectations, the authors find using German survey data that the 'tone' of an article may bias expectations, as they react more strongly to negative news. Similarly, Soroka (2006) reports that the media themselves report negative news more extensively than positive news, resulting in asymmetric news coverage. Furthermore, media reports may influence the dispersion of inflation perceptions and expectations across households, as shown by Maag and Lamla (2009) and Badarinza and Buchmann (2009).

This chapter adds to the literature by conducting an empirical analysis of the framework proposed in Ranyard et al. (2008). Thus, we aim at analyzing in detail the interrelation of inflation expectations and inflation perceptions by evaluating both their formation process and feedback-effects between the variables, accounting for actual inflation. Throughout the analysis, special emphasis is given to the role of social amplification via media reports on inflation. Furthermore, we compare results for the case of a low-inflation regime, as seen in Sweden from January 1998 to December 2007, to those from extending the sample period to include high and volatile inflation caused by a price hike in energy and food prices in 2008. The study is conducted using monthly quantitative survey data of households' inflation expectations and perceptions from the Swedish Consumer Tendency Survey and a unique data set on media reports about inflation from the media research institute Mediatenor.

Results from both long-run single-equation and SVEC estimations suggest that in the stable inflation regime inflation expectations are formed on the basis of perceived, rather than actual, inflation, while perceptions are affected by lagged inflation and only to a lesser extent by expectations. Media reports about inflation generally seem to have only small effects. Granger causality runs from inflation expectations to perceptions both in the short and in the long run, suggesting that past expectations are predictive for perceptions. By contrast, once high and volatile inflation in 2008 is included into the sample period, we see more interaction between inflation perceptions and expectations, while actual inflation becomes less important. Furthermore, the media are found to exert a much stronger influence especially on inflation perceptions, where we find asymmetric media effects related to negative news. Granger causality tests also find reverse causation between inflation perceptions and expectations, as well as short-run causality from the media to perceived inflation.

The remainder of the chapter is structured as follows: Data descriptions and initial test results for unit roots and cointegration are given in section 5.2. Section 5.3 presents results of rationality tests for inflation expectations and perceptions, as well as regressions evaluating the formation process and the role of media reports. The nature of interrelations between inflation expectations and perceptions is analyzed in Section 5.4, estimating SVEC models and testing for Granger causality. Finally, section 5.5 concludes.

5.2 Data Set and Statistical Properties

5.2.1 Inflation Perceptions and Expectations

Data for monthly inflation perceptions and expectations is obtained from the Swedish Consumer Tendency Survey for the time-span January 1996 to March 2010. The survey has been conducted on a monthly basis since 1993, originally by Statistics Sweden, between 2002 and 2008 by GfK and since October 2009 by CMA Research AB. Responses from 1993 to 2001 have been processed by the National Institute of Economic Research, the responsible statistics agency, in order to ensure comparability with later surveys. During the first two weeks of each month, a random sample of about 1,500 individuals is interviewed via telephone, where the target population is the Swedish public aged 16 to 84.[3]

The Swedish Consumer Tendency survey coincides with the Joint Harmonized EU Program of Business and Consumer Surveys conducted by the European Commission. However, in addition to questions Q5 and Q6 asking for a qualitative measure of inflation perceptions and expectations, respectively, the Swedish survey also asks respondents for

[3] For further information on the Swedish Consumer Tendency Survey and the full questionnaire, see www.konj.se. The survey is also discussed in detail in Palmqvist and Strömberg (2005).

a quantitative evaluation of perceived and expected inflation. The questions asking for quantitative inflation perceptions and expectations read as follows:

5a–b. "Compared with 12 months ago, how much higher in percent do you think that prices are now? (Average)"

6a–b. "Compared with today, how much in percent do you think that prices will go up (i.e. the rate of inflation 12 months from now)?"

The quantitative questions are located in the questionnaire directly after the qualitative questions asking about "prices in general", so that the framing of the questions with regard to CPI inflation seems well identified. We use average responses to questions 5a–b. and 6a–b. as our measure of inflation perceptions (π^p) and inflation expectations (π^e), respectively.[4]

5.2.2 Media Data

The data on media reports about inflation is taken from a unique data set for Sweden assembled by the media research institute Mediatenor.[5] For the time-span of January 1998 to December 2008, all articles related to inflation that were published in the Swedish newspaper 'Svenska Dagbladet' were coded according to a codebook in line with the standards of media content analysis. The codebook comprises all details regarding the coding of the content of articles and allows for an objective and reproducible evaluation of the media content. Aspects of each article coded include, *inter alia*, placement in the newspaper, news source, country covered, tone of the article and aspect of inflation covered. Robustness of the data is achieved by continuous training of coding specialists as well as inter-coder reliability and sample quality tests, where articles are encoded by several analysts to ensure a high level of coding accuracy. For reasons of resource restrictions, not all media contents in Sweden could be coded. Therefore, the Dagbladet as the biggest newspaper in the country was chosen to represent the defining medium that other media sources rely on for information.

In addition to the total number of articles (*vol_articles*) related to inflation in a given month, the data set comprises several more detailed variables:

[4] The Swedish Consumer Tendency survey does not provide the median of answers across respondents. Rather, mean responses corrected for extreme values of inflation perceptions and expectations are available. We checked for robustness of all our results with respect to the corrected measures. Since we found no significant changes in the results, we use the encompassing mean of all survey answers in this study.

[5] See www.mediatenor.com.

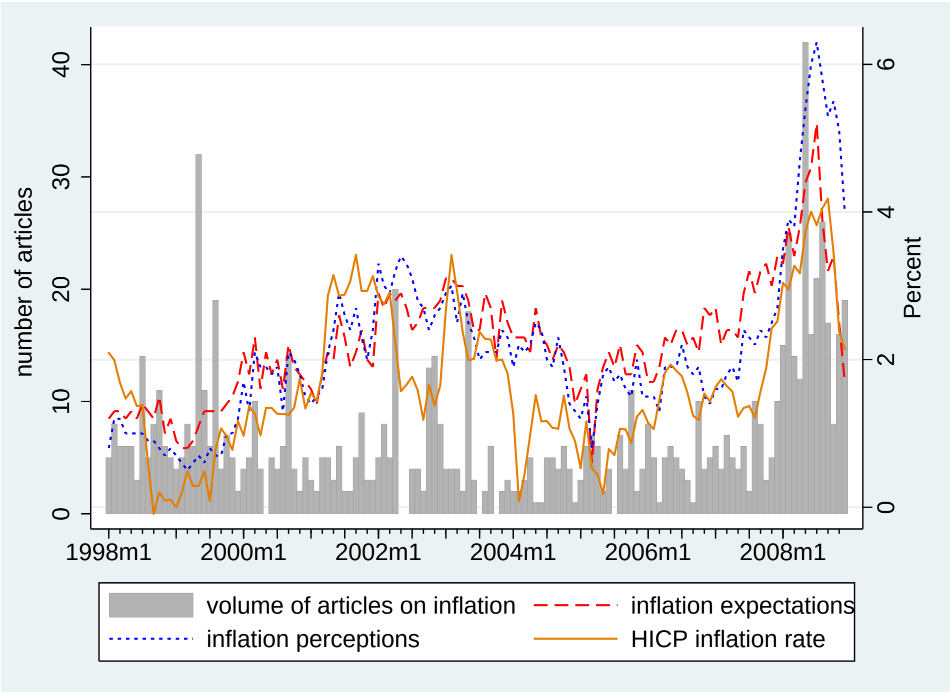
- $vol^{\pi\ increase}$ – the number of articles dealing with increasing inflation.
- $vol^{\pi\ decrease}$ – the number of articles dealing with decreasing inflation.
- $vol^{\pi\ highlevel}$ – the number of articles dealing with high inflation.
- $vol^{\pi\ lowlevel}$ – the number of articles dealing with low inflation.
- $vol^{positive}$ – the number of articles written in a positive tone.
- $vol^{neutral}$ – the numer of articles written in a neutral tone.
- $vol^{negative}$ – the number of articles written in a negative tone.
- $vol^{housing}$ – the number of articles dealing with price changes in housing.
- vol^{food} – the number of articles dealing with price changes in food.
- vol^{energy} – the number of articles dealing with price changes in energy.

From these media variables, we constructed the following aggregates to be used as explanatory variables:

- $vol\_tone = vol_t^{\pi\ increase} + vol_t^{\pi\ decrease} + vol_t^{\pi\ highlevel} + vol_t^{\pi\ lowlevel}$
- $vol\_tone^{subj} = vol^{positive} + vol^{negative}$
- $vol\_energyfood = vol^{energy} + vol^{food}$

While the variable vol_tone contains all articles whose objective topic could induce households to interpret the article as good or bad news regarding inflation, the variable vol_tone^{subj} includes articles that subjectively suggest by the tone they are written in that the content of the article is either good or bad news. Thus, whereas the former variable could cause a bias if households are particularly averse to high or low inflation, the latter variable seems more likely to directly induce a bias by the implications of its subjective tone. However, vol_tone^{subj} should to some extent be intepreted cautiously as it contains the variables most likely prone to error by the coder. Finally, $vol\_energyfood$ summarizes articles on price changes that seem likely to have a particulary strong effect on inflation expectations and perceptions: Both price changes in food and in energy usually cause wide public discussions. While price changes in food items might particularly affect inflation perceptions due to the availability bias, price changes in energy could serve as a business cycle indicator for inflation expectations.

Figure 5.1: Actual, Perceived and Expected Inflation and Articles on Inflation

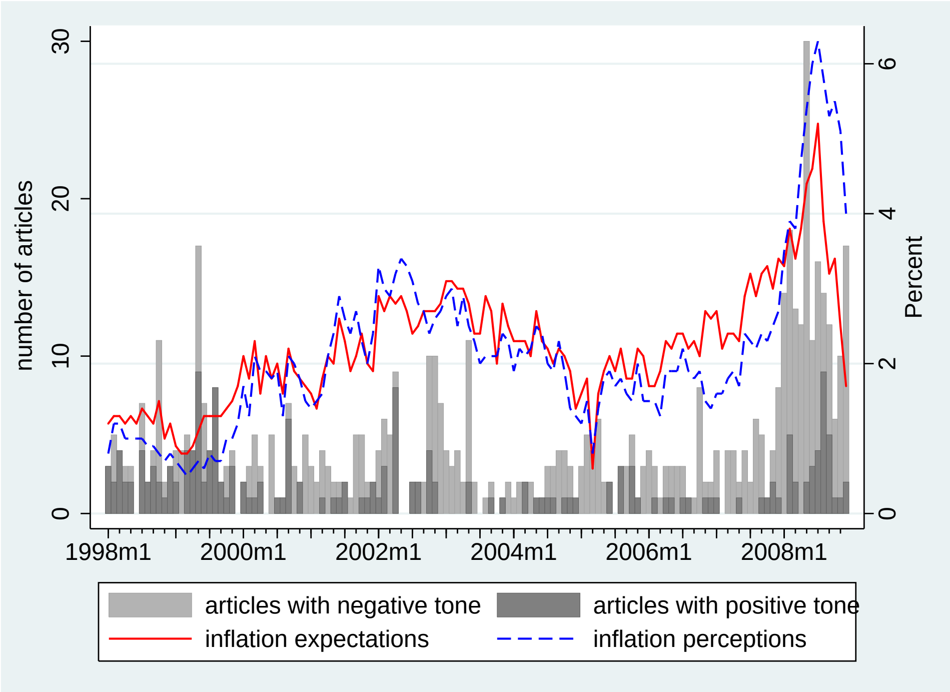


Note that the media variables are not mutually exclusive since one article may belong to several media categories.

Figure 5.1 depicts quantitative inflation perceptions and expectations from the Swedish Consumer Tendency Survey together with actual HICP inflation and the total volume of articles about inflation from our Mediatenor data set. It seems that over the sample period perceptions and expectations generally moved closely together and also in line with actual inflation. Nevertheless, from 2003 onwards perceptions and expectations were consistently higher than actual inflation, with perceptions being closer to actual inflation than expectations from 2006m1–2007m11. When food and energy prices pushed up inflation from December 2007 onwards, a rapid increase in both perceptions and expectations occurred.[6] The spike was particularly strong for perceptions and did not match actual inflation rates. The volume of articles on inflation shows a similar pattern: We see a strong increase in media coverage on inflation in 2008, while beforehand the

[6]While the spike in inflation, perceptions and expectations at the end of the sample period is an obvious outlier, a recursive Chow test also finds a structural break at the end of 2003, when perceptions and expectations started to remain higher than actual inflation. Hence, we checked for robustness of our results when splitting the sample in 2003m12 instead of estimating models including or excluding the spike in 2008. However, we found that results did not differ dramatically and indeed seem to be driven by events in the last year of the sample. For ease of exposition, we therefore compare results for the recursive samples 1998m1–2007m12 and 1998m1–2008m12 throughout.

Figure 5.2: Perceived and Expected Inflation with Positive and Negative News



number of articles was relatively stable. The strong media coverage about inflation in 2008 continued as actual inflation rates fell dramatically when the financial crisis took hold. A few spikes in the number of articles mark periods of increasing or declining inflation rate, where the outlier at the end of 1999 could be due to a strong increase of oil prices during that period.

Figure 5.2 plots perceptions and expectations together with the number of articles with a subjective positive or negative tone summarized in the variable vol_tone^{subj}. It seems that inflation perceptions, and to a slightly lesser extent also expectations, are positively correlated with articles written in a negative tone and negatively correlated with articles that have a positive tone. Overall, news about inflation seem to be predominantly depicted as negative, rather than positive, news. Nevertheless, the period of low perceptions and expectations at the beginning of the sample, as well as the sharp drop after the spike before the financial crisis, are both accompanied by a higher number of articles with a positive tone regarding inflation.

5.2.3 Macroeconomic Data

In addition to the data on expectations, perceptions and media reports, we use a number of control variables in our analysis. Actual monthly inflation rates (π) are constructed from the harmonized consumer price index for Sweden, from which we calculate year-on-year inflation rates. The timing of the inflation series thus coincides with the rate of inflation asked for in the Consumer Tendency Survey.

Additional macroeconomic and monetary aggregates are an indicator of industrial production ($prod^{industry}$), the harmonized monthly unemployment rate (U), long-term interest rates defined as the 10-year yield on government bonds (i^{long}), short-term interest rates defined as 3-months treasury bills (i^{short}) and the growth rate of money supply M2 ($m2$). All variables are obtained from the OECD Main Economic Indicators Database and are available for the sample period February 1998 to January 2010.

5.2.4 Unit Roots and Cointegration

Before proceeding to the econometric analysis, we test all variables for unit roots in order to avoid spurious results. A detailed description of all unit root and cointegration tests is given in the appendix in chapter D. Table D.1 in the appendix in chapter D summarizes results of various tests for unit roots, or stationarity, in actual, expected and perceived inflation, as well as the volume of media articles.[7] While test results reject the null of a unit root in the volume of articles (and all other media variables), there is some evidence of non-stationarity of actual as well as expected inflation and all unit root tests imply non-stationarity of perceived inflation.

Thus, we proceed to test for cointegration between the variables, where results of the Johansen (1991, 1995) tests are presented in Table D.1 in the appendix in chapter D. All tests suggest one cointegration relation when testing in bivariate vector error correction models (VECMs) between actual, perceived and expected inflation or two cointegration relations when testing in a trivariate model. This result is in line with findings in Lein and Maag (2011) and in the previous chapter 4, where we find evidence of panel-cointegration between actual and perceived inflation for European samples. For the empirical analysis, estimations are hence done either in levels, specifying long-run relationships, or in the framework of error correction models.

[7] The remaining media variables were also tested for unit roots and results were in line with those for $vol\_articles$. With respect to macro and money aggregates, we found a unit root in $prod^{industry}$, U, i^{long} and i^{short} and therefore use differences of these variables in all regressions. Results for the unit root tests are not reported here due to space limitations, but can be obtained from the author upon request.

5.3 The Formation Process and the Media

In this section, we analyze the formation process of inflation perceptions and expectations. First, we evaluate the concept of rationality by testing for accuracy, a bias and efficiency in perceived and expected inflation. Second, results of single-equation models describing long-term relations between perceptions and expectations and the role of media reports on inflation are presented.

5.3.1 Rationality Tests

In line with the literature, we test for rationality of inflation perceptions and expectations by evaluating three different aspects of rationality, namely accuracy, unbiasedness and efficiency: First, both perceptions and expectations should be as accurate as possible with respect to actual present and future values of inflation, respectively. We analyze accuracy by reporting mean absolute errors (MAE) and root mean squared errors (RMSE), which are normalized by average inflation over the sample period. In comparison with the MAE, the RMSE emphasizes the effect of large forecast errors.[8]

Next, we test for a bias with respect to inflation perceptions and expectations, respectively. Under the null hypothesis of no bias, today's inflation perceptions as well as inflation expectations one year ago should be an unbiased predictor of today's actual inflation rate. Hence, we estimate the regressions

$$\pi_t = \alpha + \beta\pi_t^p + \epsilon_t \tag{5.1}$$

$$\pi_t = \alpha + \beta\pi_{t-12}^e + \epsilon_t \tag{5.2}$$

and test for the joint null hypothesis $H_0 : (\alpha, \beta) = (0, 1)$. In order to account for the cointegration between π and π^p or π^e, respectively, we estimate (5.1) and (5.2) in a vector error correction model (VECM) and test for H_0 regarding the cointegration relations contained in the cointegrating vector. The test is conducted with a Wald test estimated using the Johansen Maximum Likelihood estimator. Furthermore, we present results of Wilcoxon (1945) signed-rank tests for the null hypothesis if $H_0 : \pi_t = \pi_t^p$ and $H_0 : \pi_t = \pi_{t-12}^e$, respectively.[9] With the advantage of being unaffected by

[8]Batchelor and Dua (1987), Thomas (1999) and Forsells and Kenny (2002) test for accuracy of inflation expectations in the UK, the US and the Euro area, respectively. Lein and Maag (2011) analyze MAE and RMSE of inflation perceptions for a sample of European countries including Sweden.

[9]Dufour (1981) presents a similar non-parametric test for serial dependence.

non-normal distributions, this non-parametric test procedure tests for the equality of matched pairs of observations by assuming that both distributions are the same. After forming differences between the variables, they are ranked according to their absolute value and then signed with the sign of the original difference. The test statistic is given either by the sum of positive or negative signed ranks, depending on which is smallest.[10]

Finally, we complete the rationality tests by evaluating whether perceptions and expectations efficiently incorporate available information. Differentiating between the concepts of weak-form and strong-form efficiency, we first test if perception or expectation errors are persistent or significantly correlated with lagged inflation rates. Second, strong-form efficiency is tested by regressing errors on a larger set of macroeconomic and monetary aggregates. All variables are lagged by 13 months in order to exclude the possibility of overlapping errors within the 12-month horizon of forecasts/backcasts and to allow for one publication lag: In the case of forward-looking expectations 12 months ahead, a random forecast error in a particular month would also be included in the subsequent 11 forecasts, since only then actual inflation rates are revealed. By contrast, since perceptions are backcasts of inflation over the past 12 months, any error could in principle be corrected as actual inflation rates become available each month. However, this imposes a rather strict concept of rationality on inflation perceptions, therefore, we relax the test by only including variables with a lag of 13 months.[11]

To avoid spurious results, we use first differences of all variables that were found to be non-stationary.[12] Estimation results are presented with Newey-West standard errors that are robust to serial correlation and heteroscedasticity in the residuals. We present results of the rationality tests for the whole sample period 1998m1–2008m12, since test results for the low-inflation period 1998m1–2007m12 did not differ significantly.[13]

Table 5.1 presents results of the three rationality tests for inflation perceptions in Sweden. Both the normalized MAE (0.40) and RMSE (0.52) are relatively high, considering that inflation perceptions are based on actual inflation and should thus be less

[10]Most studies cited above that analyze the rationality of inflation perceptions and expectations test for a bias in a regression set-up as in equations (5.1) and (5.2). However, only Dias et al. (2010) account for the non-stationarity and cointegration of inflation expectations and actual inflation.

[11]Weak-form or strong-form efficiency with respect to inflation expectations is also tested by Batchelor and Dua (1987) for the UK, by Thomas (1999), Mankiw et al. (2004) and Souleles (2004) for the UK as well as by Forsells and Kenny (2002) and Dias et al. (2010) for European economies. Jonung and Laidler (1988) as well as Lein and Maag (2011) test for strong-form efficiency of inflation perceptions.

[12]For unit root tests on actual, perceived and expected inflation as well as *vol_articles*, see table D.1 in the appendix. Test results of unit root tests on the remaining variables are available from the author upon request.

[13]Results are available from the author upon request.

Table 5.1: Testing Rationality of Inflation Perceptions

Accuracy:		MAE	RMSE
		0.4027	0.5213
Bias: $\pi_t = \alpha + \beta\pi_t^p$	F-stat./z-stat.	prob.	
H_0:$(\alpha, \beta) = (0, 1)$	16.0533	0.000	VECM, 12 Lags
H_0: $\pi_t = \pi_t^p$	-6.521	0.000	Wilcoxon signed-rank test
Efficiency: π^p_error	(1)	(2)	(3)
$\pi^p\_error_{t-13}$	-.1856		
	(.1535)		
$d(\pi)_{t-13}$		-.5188***	-.4636***
		(.1333)	(.1613)
$d(\pi^p)_{t-13}$			.0775
			(.1804)
$d(\pi^e)_{t-13}$			-.0587
			(.1396)
$d(prod^{industry})_{t-13}$			.0214
			(.0214)
$d(U)_{t-13}$			.0565
			(.0866)
$d(i^{long})_{t-13}$			-.7189**
			(.3233)
$d(i^{short})_{t-13}$			.5745
			(.6363)
$m2_{t-13}$			-3.9044
			(5.0107)
$vol\_articles_{t-13}$			.0101
			(.0089)
ADF test resid.	-3.606	-3.977	-4.169
1% critical value	-2.598	-2.598	-2.598

Note: Newey-West standard errors in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.
Sample period: 1998m1–2008m12.

Table 5.2: Testing Rationality of Inflation Expectations

Accuracy:		MAE	RMSE
		0.4844	0.6005
Bias: $\pi_t = \alpha + \beta\pi^e_{t-12}$	F-stat./z-stat.	prob.	
H_0:$(\alpha, \beta) = (0, 1)$	34.6822	0.000	VECM, 12 Lags
H_0: $\pi_t = \pi^e_{t-12}$	-3.983	0.000	Wilcoxon signed-rank test
Efficiency: π^e_error	(1)	(2)	(3)
$\pi^e\_error_{t-13}$	.1319		
	(.1755)		
$d(\pi)_{t-13}$		-.1505	-.0795
		(.2116)	(.2545)
$d(\pi^e)_{t-13}$			-.0827
			(.1690)
$d(\pi^p)_{t-13}$			.0384
			(.1718)
$d(prod^{industry})_{t-13}$			-.0417
			(.0454)
$d(U)_{t-13}$			-.0399
			(.1394)
$d(i^{long})_{t-13}$			-.3351
			(.5435)
$d(i^{short})_{t-13}$			1.8473*
			(.9533)
$m2_{t-13}$			5.3637
			(6.1947)
$vol\_articles_{t-13}$			.0218
			(.0187)
ADF test resid.	-2.881	-2.985	-3.330
1% critical value	-2.599	-2.598	-2.598

Note: Newey-West standard errors in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% level, respectively.
Sample period: 1998m1–2008m12.

prone to inaccuracy than inflation expectations. Lein and Maag (2011) report similar results using Swedish data for the time span of 1993–2007. With respect to a bias in perceptions, both the Wald test from a VECM estimation and the non-parametric Wilcoxon signed-rank test reject the null hypothesis of no bias in inflation perceptions at the 1% level. In line with the results regarding accuracy, it thus seems that inflation perceptions in Sweden do not relate one-to-one to actual inflation. Finally, we find evidence of both weak- and strong-form inefficiency: While perception errors are not significantly correlated with errors 13 months ago, changes in actual inflation in t-13 significantly reduce perception errors. This finding remains robust when we include a larger set of explanatory variables. Additionally, we find that past information about changes in long-term interest rates significantly reduces perception errors.

Results of the rationality tests for inflation expectations in Sweden are given in Table 5.2. Regarding the accuracy of inflation forecasts, both the MAE (0.48) and RMSE (0.60) are larger than those found with respect to perceptions. This is not surprising, since inflation expectations are formed with respect to an uncertain future, while perceptions relate to actual values of inflation. Nevertheless, these values indicate that also inflation expectations are to some degree formed inaccurately. Testing for a bias in inflation expectations, both the Wald test in a VECM setting and the Wilcoxon signed-rank test reject the null of no bias at the 1% level. However, in contrast to our results for inflation perceptions, we find little evidence of inefficiency of expectations. Only changes in short-term interest rates 13 months ago yield a weakly significant coefficient, albeit with a positive coefficient.

5.3.2 Perceived and Expected Inflation and the Role of Media Reports

After having rejected rationality, we turn to analyzing the formation process of perceptions and expectations in more detail. Specifically, we analyze correlations between the variables and actual inflation as well as the role of media reports on inflation, where we distinguish between different aspects of media reports on inflation. We estimate all regressions in levels, so that results may be regarded as long-term relationships and should be super-consistent due to cointegration between the inflation variables. A lagged endogenous variable is included in all models in order to account for the persistence of the variables.

Since the survey interviews are conducted in the first two weeks of each month, official statistics for that month's inflation rate might not yet be available and media articles of that month could be published also after the interviews. In order to avoid any bias due to publication lag, we thus lag actual inflation and all media variables by one month.

Furthermore, endogeneity tests suggest an endogeneity problem with respect to inflation perceptions and expectations, respectively. The endogeneity test shown in Tables 5.3 to 5.6 analyzes the null that a specified endogenous regressor may in fact be treated as exogenous. It is constructed as the difference of the Hansen-Sargent statistics from two models, where the regressor is treated as endogenous or as exogenous, respectively, and has a $\chi^2(1)$ distribution. In response to the results, we estimate all models using the general method of moments (GMM) estimator and instrumenting for inflation expectations and perceptions, respectively, with their first and twelfth lags. Generally, the underidentification test showing the Kleibergen and Paap (2006) LM statistic for the null that excluded instruments are not correlated with the endogenous regressor can be rejected or misses significance only marginally, while the Hansen (1982) J statistic cannot reject the null hypothesis that all instruments are valid in the sense that they are uncorrelated with the error term. Standard errors reported are robust to heteroscedasticity and autocorrelation. For models containing only past inflation as explanatory variable, we employ the OLS estimator with Newey-West standard errors. All results are compared for estimation periods covering the low-inflation period 1998m1–2007m12 to those for an extended sample period including the high-inflation year 2008.

Tables 5.3 to 5.4 show estimation results of single-equation models explaining inflation perceptions in Sweden. For the estimation period 1998m1–2007m12, results suggest that inflation perceptions are based largely on lagged actual inflation, while (instrumented) inflation expecations and media reports play no significant role. However, when extending the sample to include the high-inflation period in 2008, we find that both expected and lagged actual inflation rates significantly and positively affect perceived inflation, suggesting some form of expectancy confirmation behavior as in Traut-Mattausch et al. (2004).

Regarding the effect of media reports about inflation on perceptions in the extended sample 1998m1–2008m12, we find that the volume of articles on inflation significantly raises inflation perceptions, albeit with a small coefficient. However, when distinguishing between the effects of media reports on rising, falling, high and low inflation, we find that only 'bad news' reporting either increasing or a high level of inflation significantly raise inflation perceptions, while coefficients on articles about falling or low inflation remain insignificant. This result could be related to households' loss aversion with respect to above-average inflation as analyzed in chapter 4, which might lead to an asymmetric

Table 5.3: Inflation Perceptions and the Media

π_t^p	(1)	(2)[1]	(3)	(4)	(5)	(6)	(7)
π_{t-1}^p	.8764***	.8429***	.7919***	.7675***	.7579***	.7632***	.7801***
	(.0889)	(.0567)	(.0718)	(.0732)	(.0691)	(.0693)	(.0743)
π_t^e	.0612		.0695	.0696	.0561	.0689	.0428
(instrumented)	(.1114)		(.0930)	(.0938)	(.0941)	(.0927)	(.0959)
π_{t-1}		.0919**	.1004**	.1185***	.1166***	.1153***	.1287***
		(.0455)	(.0415)	(.0375)	(.0360)	(.0377)	(.0397)
$vol\_articles_{t-1}$				-.0032			
				(.0048)			
$vol_{t-1}^{\pi\ increase}$					-.0064		
					(.0115)		
$vol_{t-1}^{\pi\ decrease}$					.0004		
					(.0474)		
$vol_{t-1}^{\pi\ highlevel}$					.0084		
					(.0144)		
$vol_{t-1}^{\pi\ lowlevel}$					-.0216		
					(.0157)		
$vol_{t-1}^{positive}$						-.0009	
						(.0194)	
$vol_{t-1}^{neutral}$						-.0078	
						(.0120)	
$vol_{t-1}^{negative}$						-.0018	
						(.0120)	
$vol_{t-1}^{housing}$							.0406
							(.0388)
vol_{t-1}^{food}							-.0152
							(.0344)
vol_{t-1}^{energy}							-.0022
							(.0104)
centered R^2	0.840	-	0.848	0.850	0.849	0.851	0.846
Endog. test π^e	4.403**	-	6.820***	6.666***	7.925***	7.583***	6.642***
Kleibergen/Paap LM	4.045	-	6.269**	6.199**	7.108**	6.902**	7.611**
Hansen J stat.	0.805	-	1.253	0.933	0.773	0.785	1.238

Note: GMM with robust standard errors in parentheses. *, **,*** denote significance at the 10%, 5%, 1% level, respectively. Sample period: 1998m1–2007m12. [1]OLS with Newey-West standard errors.

Table 5.4: Inflation Perceptions and the Media including the High Inflation Year 2008

π_t^p	(1)	(2)[1]	(3)	(4)	(5)	(6)	(7)
π_{t-1}^p	.8917***	.8784***	.8177***	.7756***	.7585***	.7664***	.7607***
	(.0338)	(.0473)	(.0477)	(.0496)	(.0456)	(.0483)	(.0330)
π_t^e	.1226*		.1311*	.1468**	.1367**	.0967	.1442**
(instrumented)	(.0744)		(.0751)	(.0714)	(.0569)	(.0624)	(.0617)
π_{t-1}		.1314**	.1162***	.1411***	.1389***	.1410***	.1304***
		(.0539)	(.0424)	(.0429)	(.0450)	(.0397)	(.0376)
$vol\_articles_{t-1}$				.0072*			
				(.0040)			
$vol_{t-1}^{\pi\ increase}$					.0239*		
					(.0134)		
$vol_{t-1}^{\pi\ decrease}$					.0100		
					(.0369)		
$vol_{t-1}^{\pi\ highlevel}$					.0239*		
					(.0141)		
$vol_{t-1}^{\pi\ lowlevel}$					-.0112		
					(.0114)		
$vol_{t-1}^{positive}$						-.0132	
						(.0146)	
$vol_{t-1}^{neutral}$						-.0247**	
						(.0125)	
$vol_{t-1}^{negative}$						.0295***	
						(.0109)	
$vol_{t-1}^{housing}$							.0353
							(.0264)
vol_{t-1}^{food}							.0756**
							(.0362)
vol_{t-1}^{energy}							-.0145
							(.0119)
centered R^2	0.930	-	0.935	0.938	0.940	0.937	0.942
Endog. test π^e	5.201**	-	5.561**	5.268**	4.655**	5.396**	5.175**
Kleibergen/Paap LM	3.843	-	4.214	4.067	4.360	3.993	4.463*
Hansen J stat.	0.287	-	0.001	0.126	1.235	0.008	0.124

Note: GMM with robust standard errors in parentheses. *, **, *** denote significance at the 10%, 5%, 1% level, respectively. Sample period: 1998m1–2008m12. [1]OLS with Newey-West standard errors.

perception of media news that can bias perceptions.[14] Similarly, articles with a negative tone have a significantly positive coefficient, while the coefficient on articles with a positive tone is not significant, albeit negatively signed. However, neutral articles are also found to significantly reduce inflation perceptions. Finally, articles related to price changes of food items significantly increase inflation perceptions. This result could be indicative of the higher availability of price changes in frequently bought goods as hypothesized in chapter 4. Media reports on food-related inflation might thus trigger the availability effect, thus producing a further media-related bias to perceptions.[15] Overall, it thus seems that when accounting for periods of high and volatile inflation, perceived inflation rates are influenced significantly, and possibly biased, by the media.

Estimation results for the formation process of inflation expectations are given in Tables 5.5 and 5.6. Regarding the stable inflation regime until 2007, we find that inflation expectations are significantly correlated with their respective perceptions of inflation, while lagged actual rates play no role. The result that inflation expectations are largely based on perceptions is in line with findings in Jonung (1981), van der Klaauw et al. (2008) and Maag (2010b). However, once we include the period of high inflation rates in 2008, estimation results show that lagged actual inflation rates in most models significantly affect expectations, while perceptions remain insignificant.[16]

Regarding the role of media reports for inflation expectations, we find some media effects already in the low-inflation regime: Inflation expectations increase with the number of articles on increasing inflation and on housing prices. While the number of articles on low inflation has a significantly dampening effect on expectations, the effect of articles about decreasing inflation is wrongly signed with a positive coefficient. Extending the sample period until 2008m12, in addition to the effects of articles about increasing or low level inflation, we find a similar effect of news with a positive or negative tone. Overall, it thus seems that inflation expectations in Sweden are not affected asymmetrically by media reports, in contrast to inflation perceptions.[17] Finally, including the high inflation year 2008, media reports on energy price changes seem to trigger a reduction in inflation

[14]Note that coefficients on $vol_{t-1}^{\pi\_increase}$ and $vol_{t-1}^{\pi\_decrease}$, as well as on $vol_{t-1}^{\pi\_highlevel}$ and $vol_{t-1}^{\pi\_lowlevel}$, are not statistically different from each other. However, only the former are significantly different from zero, while the latter have no significant impact on perceptions.

[15]Empirical evidence of the availability effect on inflation perceptions is given in Döhring and Mordonu (2007), Lein and Maag (2011) and in chapter 4.

[16]Note that the decrease in centred R^2 from model (1) to models (3), (4), (6) and (7) is due to changes in the significance of the constant, which is not reported here.

[17]This result is in contrast to findings in Lamla and Lein (2008), who find that German inflation expectations reacted more strongly to negative news.

Table 5.5: Inflation Expectations and the Media

π^e_t	(1)	(2)[1]	(3)	(4)	(5)	(6)	(7)
π^e_{t-1}	.7348***	.8301***	.7317***	.7319***	.7007***	.7127***	.6314***
	(.1147)	(.0763)	(.1155)	(.1163)	(.0882)	(.1046)	(.0737)
π^p_t	.1814**		.1948*	.1778*	.1511**	.1712*	.2333***
(instrumented)	(.0909)		(.1009)	(.0989)	(.0711)	(.0955)	(.0776)
π_{t-1}		.0533	-.0102	.0063	-.0117	.0086	.0057
		(.0398)	(.0323)	(.0275)	(.0328)	(.0311)	(.0366)
$vol\_articles_{t-1}$				.0005			
				(.0036)			
$vol^{\pi\ increase}_{t-1}$					.0338***		
					(.0097)		
$vol^{\pi\ decrease}_{t-1}$					.0970**		
					(.0479)		
$vol^{\pi\ highlevel}_{t-1}$					.0074		
					(.0136)		
$vol^{\pi\ lowlevel}_{t-1}$					-.0521***		
					(.0203)		
$vol^{positive}_{t-1}$						-.0232	
						(.0168)	
$vol^{neutral}_{t-1}$						.0040	
						(.0188)	
$vol^{negative}_{t-1}$						.0034	
						(.0117)	
$vol^{housing}_{t-1}$							.1142**
							(.0488)
vol^{food}_{t-1}							.0136
							(.0291)
vol^{energy}_{t-1}							.0121
							(.0103)
centered R^2	0.788	-	0.791	0.786	0.800	0.787	0.815
Endog. test π^e	4.527**	-	4.704**	4.551**	6.830***	6.219**	5.843**
Kleibergen/Paap LM	5.297*	-	5.612*	4.857*	6.112**	6.107**	6.986**
Hansen J stat.	1.547	-	1.452	1.391	2.011	0.997	2.765*

Note: GMM with robust standard errors in parentheses. *, **, *** denote significance at the 10%, 5%, 1% level, respectively. Sample period: 1998m1–2007m12. [1]OLS with Newey-West standard errors.

Table 5.6: Inflation Expectations and the Media including the High Inflation Year 2008

π_t^e	(1)	(2)[1]	(3)	(4)	(5)	(6)	(7)
π_{t-1}^e	.9397***	.8359***	.9511***	.9443***	.8546***	.8460***	.9550***
	(.1126)	(.0648)	(.1156)	(.1208)	(.1088)	(.1083)	(.1414)
π_t^p	-.0346		-.1057	-.1219	-.1122	-.0955	-.1819
(instrumented)	(.0841)		(.1119)	(.1304)	(.1340)	(.1326)	(.1515)
π_{t-1}		.0586	.0996*	.1224**	.0822	.1091*	.1212**
		(.0379)	(.0561)	(.0599)	(.0594)	(.0560)	(.0565)
$vol\_articles_{t-1}$				.0021			
				(.0039)			
$vol_{t-1}^{\pi\ increase}$					.0561**		
					(.0220)		
$vol_{t-1}^{\pi\ decrease}$					.0275		
					(.0331)		
$vol_{t-1}^{\pi\ highlevel}$					.0087		
					(.0160)		
$vol_{t-1}^{\pi\ lowlevel}$					-.0552***		
					(.0198)		
$vol_{t-1}^{positive}$						-.0407***	
						(.0158)	
$vol_{t-1}^{neutral}$						-.0279	
						(.0237)	
$vol_{t-1}^{negative}$						.0288*	
						(.0153)	
$vol_{t-1}^{housing}$							.0735
							(.0635)
vol_{t-1}^{food}							.1287*
							(.0754)
vol_{t-1}^{energy}							-.0399**
							(.0193)
centered R^2	0.776	-	0.758	0.755	0.782	0.775	0.760
Endog. test π^e	4.421**	-	3.684*	3.637*	2.525	3.961**	1.490
Kleibergen/Paap LM	3.112	-	4.102	4.537*	4.708*	4.308	4.322
Hansen J stat.	0.518	-	0.857	0.796	2.779*	0.223	3.924**

Note: GMM with robust standard errors in parentheses. *, **, *** denote significance at the 10%, 5%, 1% level, respectively. Sample period: 1998m1–2008m12. [1]OLS with Newey-West standard errors.

expectations, while articles about food prices have a positive impact on expectations. Note that news about longer lasting housing price changes affected forward-looking inflation expectations in the low-inflation regime, while short-run volatility in food and energy prices only has an impact when including the high-inflation period.

5.4 Interrelations between Inflation Perceptions and Expectations

After the analysis of the formation process of inflation perceptions and expectations in the previous section, we turn to evaluating the nature of their interrelation. We analyze the cointegration relation as well as impulse-response functions and forecast error variance decompositions in a structural vector error correction (SVEC) model and present tests for long- and short-run Granger causality.

5.4.1 SVEC Estimations

Accounting for the cointegration between actual, perceived and expected inflation, we analyze interrelations of π, π^p, π^e and $vol\_articles$ by evaluating impulse-response functions and forecast error variance decompositions (FEVD) from an SVEC model. The model is estimated in a two-stage procedure, where the cointegration vector, assuming two cointegration relations, is estimated with the simple two step estimator (S2S) in the first stage and the remaining coefficients of the SVEC model are estimated with OLS in the second stage. In line with the information criteria, all models are estimated with 2 lags and including a constant and seasonal dummies.[18]

The SVEC model thus takes on the following form:

$$\Delta y_t = \alpha\beta' y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + C_0 D_t + u_t, \tag{5.3}$$

where $y_t = \begin{pmatrix} \pi_t & \pi_t^p & \pi_t^e & vol\_articles_t \end{pmatrix}'$ is the vector of endogenous variables, D_t includes the constant and seasonal dummies and u_t is the vector of reduced-form residuals. The cointegration relations between the variables are estimated in the matrix β, where the first column excludes actual inflation π_t and the second column excludes perceived inflation π_t^p. The first coefficient of each cointegration relation is normalized to 1. α contains the loading coefficients and Γ_1, Γ_2 and C_0 are coefficient matrices.

[18]The VECM models satisfy stability conditions and we find no evidence of autocorrelation or heteroscedasticity in the residuals. Test results are available from the author upon request.

Table 5.7: Cointegration Relation in the SVEC

1998m1–2007m12	α_1	α_2	β_1	β_2
π	0.119	-0.173***	-	1.000
	(0.109)	(0.057)		(0.000)
π^p	-0.220***	0.087**	1.000	-
	(0.068)	(0.036)	(0.000)	
π^e	-	-	-1.000***	-0.766***
			(0.000)	(0.242)
vol_articles	-	-	0.018	0.011
			(0.050)	(0.087)
Wald test on	Test-stat.	H_0		
β-restrictions	2.166	$\beta(3,1) = -1$		
	(0.141)			
1998m1–2008m12	α_1	α_2	β_1	β_2
π	-	-0.185***	-	1.000
		(0.049)		(0.000)
π^p	-0.270***	0.093***	1.000	-
	(0.058)	(0.035)	(0.000)	
π^e	-0.104*	-	-1.046***	-0.680***
	(0.063)		(0.142)	(0.245)
vol_articles	2.101**	-	-0.087***	-0.016
	(1.002)		(0.023)	(0.040)

Note: Standard errors and p-values for the Wald test in parentheses.
*,** and *** denote rejection of H_0 at the 10%, 5% and 1% level, respectively.

The coefficients governing the cointegration relation between actual, perceived and expected inflation, as well as media reports about inflation, are shown in Table 5.7 for the two sample periods. As expected, we find cointegration between inflation perceptions and expectations, as well as between actual and expected inflation, in both models: Coefficients of the cointegration relation between perceived and expected inflation in β_1 suggest a one-to-one cointegration relation between the variables, as the coefficient of π^e_{t-1} is found highly significant and close to -1. In fact, a Wald test using the Johansen ML estimator cannot reject the restriction $\beta(3,1) = -1$ in the model for the sample period 1998m1–2007m12, so that we restrict the coefficient in order to increase efficiency of the estimation. Regarding the second cointegration relation between actual and expected inflation, both models find highly significant coefficients of π^e_{t-1}, while the coefficient of π_{t-1} is again normalized to 1. As expected, the volume of articles on inflation does not feature significantly in either cointegration relation for the stable inflation period, but a Wald test rejects restricting the coefficients to zero. However, it is interesting to note that a significant, albeit small, coefficient of $vol\_articles_{t-1}$ is found in the cointegration relation between π^p and π^e when extending the sample to include the high inflation year 2008.

Analyzing the loading coefficients contained in α, we use a sequential elimination of regressors (SER) procedure based on the Akaike information criterion to restrict those loading coefficients to zero that lead to the largest reduction in the information criterion. Regarding the cointegration relation between perceived and expected inflation, we find that only π^p_{t-1} yields a significant loading coefficient in the shorter sample period, suggesting that actual and expected inflation and the media were weakly exogenous. However, extending the sample period, we find a weakly significant negative loading coefficient also for π^e_{t-1} and a large positive coefficient for $vol\_articles_{t-1}$. It thus seems that including the spike in actual, perceived and expected inflation in 2008 leads both π^p and π^e to adjust to the long-run cointegration equilibrium, while the media have a divergent effect. Nevertheless, the SVEC model remains stable.[19] Finally, loading coefficients for the second cointegration relation between actual and perceived inflation remain similar between both models, with only actual inflation adjusting to the long-run equilibrium.

[19]The finding of changes in the cointegration relation between inflation perceptions and expectations between the two sample periods could be captured in a model with threshold cointegration as suggested by Hansen and Seo (2002). However, since the break is at the end of the sample period, it would be difficult to identify without further datapoints and we would have to make a decision whether to restrict α or β. We leave this question for future research.

In order to identify impulse-response functions and FEVD, we impose restrictions on the contemporary relations between the endogenous variables with a Cholesky-decomposition of the following form:

$$\begin{pmatrix} u_t^{\pi} \\ u_t^{\pi^p} \\ u_t^{\pi^e} \\ u_t^{vol\_articles} \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 \\ b_{31} & b_{32} & b_{33} & 0 \\ b_{41} & b_{42} & b_{43} & b_{44} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{\pi} \\ \varepsilon_t^{\pi^p} \\ \varepsilon_t^{\pi^e} \\ \varepsilon_t^{vol\_articles} \end{pmatrix} \tag{5.4}$$

where u_t denotes the vector of reduced-form residuals and ε_t the vector of structural shocks. The identification is chosen based on theoretical and empirical observations: We argue that actual inflation is unlikely to be affected by perceived and expected inflation rates (or the media) in the same month due to the generally observed stickiness of prices incorporated into most modern macroeconomic models, see Calvo (1983). Also, since several authors find empirical evidence that inflation expectations are largely formed on the basis of perceived inflation (see, e.g., Benford and Driver, 2008 and Maag, 2010b), we allow for a contemporaneous effect of perceptions on expectations, but not *vice versa*. Finally, in order to account for a possible publication-lag, we only allow lagged effects of media reports on actual, perceived and expected inflation.

Figures 5.3 and 5.4 show impulse-response functions of π, π^p, π^e and $vol\_articles$ over 30 months for the two sample periods, where 95% confidence intervals were generated with 1000 bootstrap-replications using Hall's percentile interval. Calculating impulse-response functions for the stable inflation regime, as expected a one-standard-deviation increase of actual inflation causes both inflation perceptions and expectations to rise, while the media are not affected.[20] Similarly, a shock on perceived inflation causes a persistent increase of actual and expected inflation, while impulse-responses of actual and perceived inflation after a shock to expectations build up more slowly. Regarding $vol\_articles$, we find no significant effect of an unexpected rise in media reports on inflation expectations, but a small, weakly significant, negative effect on actual and perceived inflation.

By contrast, we see more interaction between perceptions, expectations and the media once the high inflation year 2008 is included in the sample period: Impulse-response functions suggest stronger effects of shocks to expectations on both perceived

[20]Note that a permanent effect of temporary shocks on the level variables is not surprising, since actual, perceived and expected inflation rates are non-stationary. Hence, while the SVEC model is estimated in first differences, shocks may lead to permanent level shifts of the non-stationary variables, as first differences return to zero when the shock dies out. By contrast, shocks on the stationary media variable have no significant long-run effects.

Figure 5.3: SVEC with π, π^p, π^e and $vol\_articles$, 1998m1–2007m12

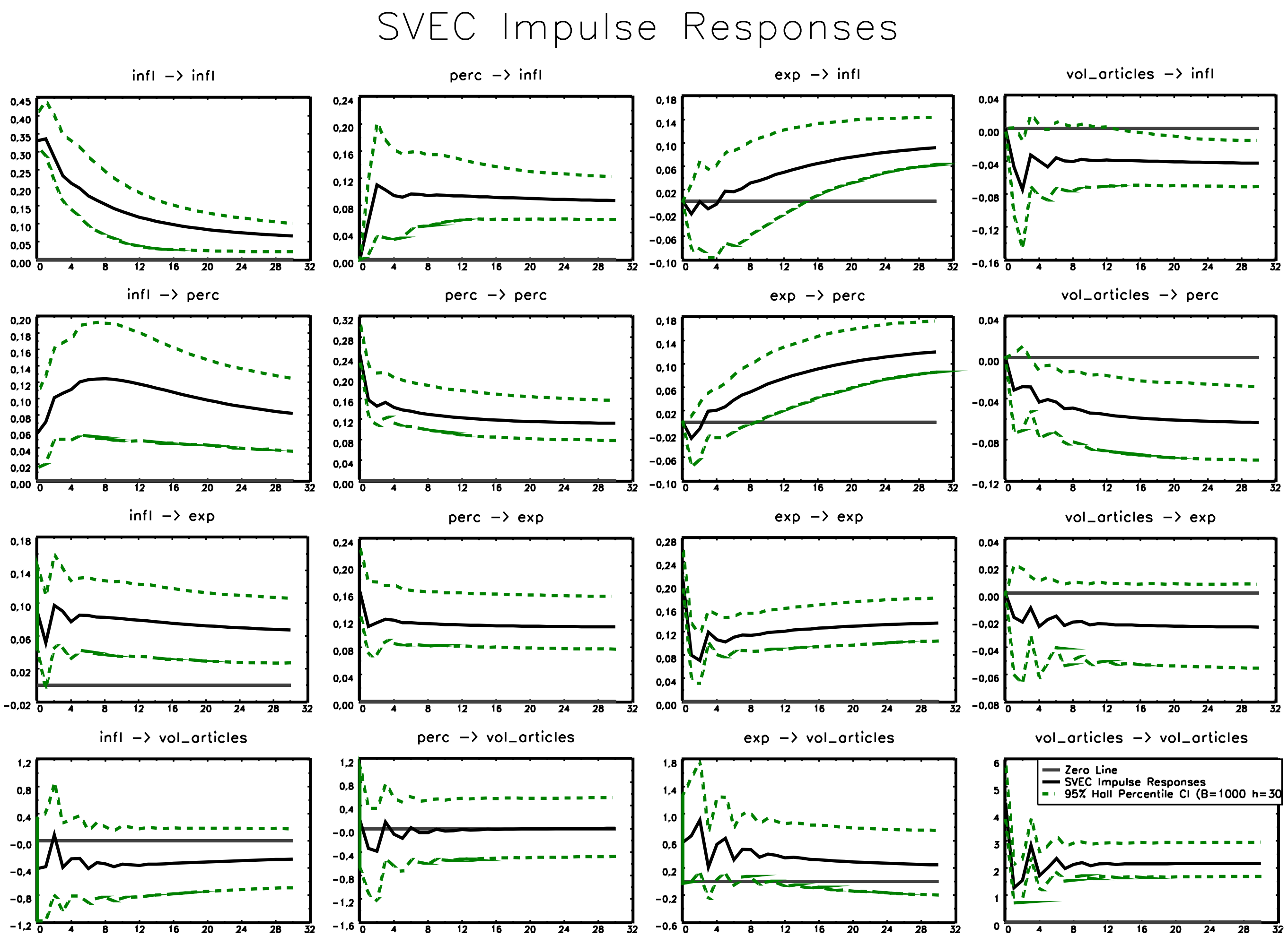
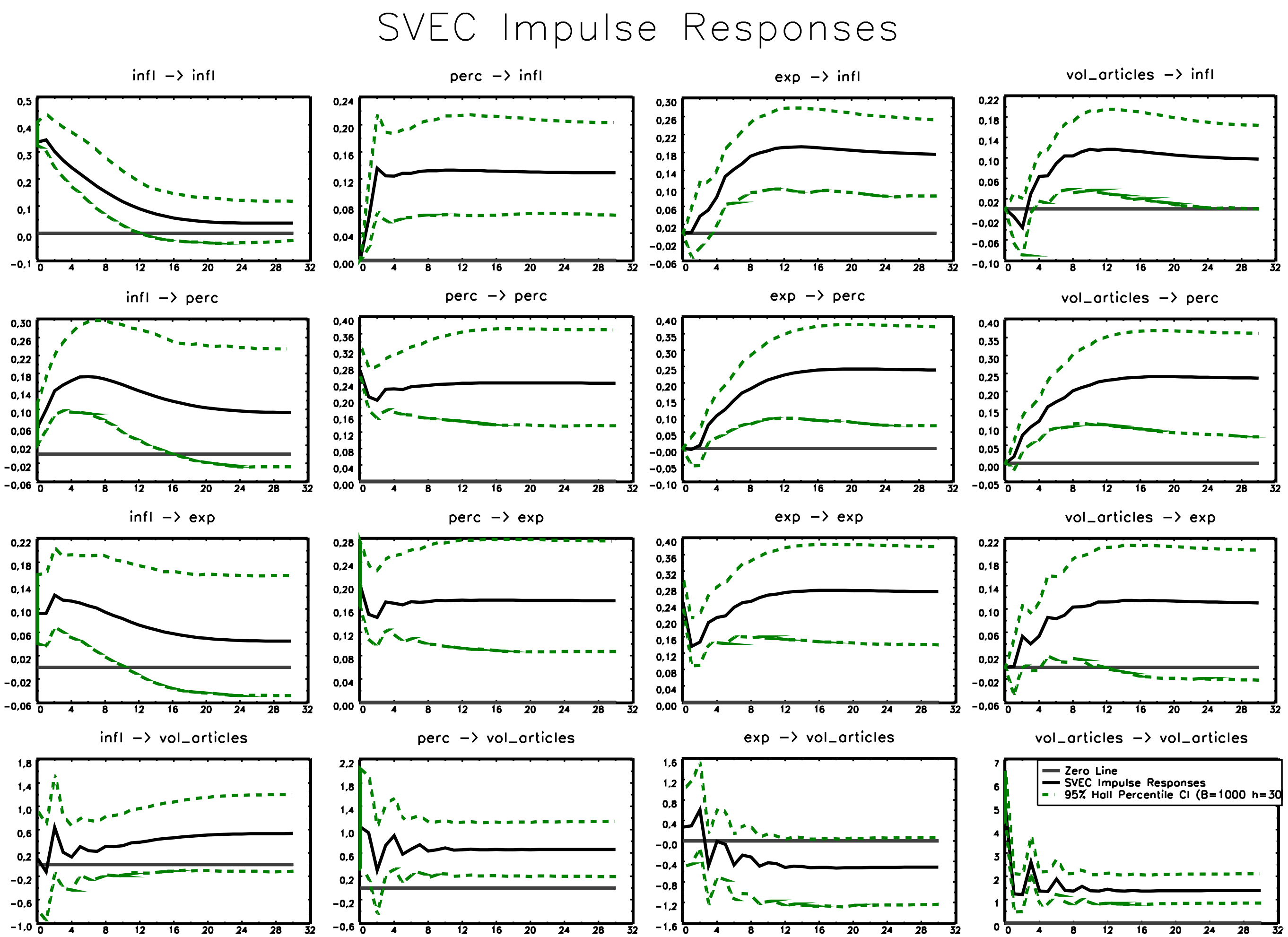


Figure 5.4: SVEC Including the High Inflation Year 2008



and actual inflation, as impulse-responses build up more quickly. Notably, the effect of shocks on actual inflation is reduced in the extended sample period, as impulse-responses of perceptions and expectations become insignificant after a few months. Finally, the stronger effect of media reports when accounting for higher inflation in 2008 also features in the impulse-response functions, where especially π^p (and π) increase significantly after a media shock, with only a small effect on π^e.

Additionally, forecast error variance decompositions are presented in Table 5.8 for both sample periods. Due to the identification of the model, the forecast error variance of inflation is unaffected by other variables in the very short run, but in the longer run both perceived and expected inflation account for about 25% and 19%, respectively. While perceived inflation also remains largely exogenous in the short run, at a longer horizon especially inflation expectations account for almost 30% of its forecast error variance, while actual inflation explains about 23% and the media only have a small effect. Expected inflation is also affected more strongly by perceived, rather than actual, inflation, as almost 35% of its forecast error variance is due to π^p already in the short run. Finally, the media appear largely exogenous in the earlier sample period.

Including high inflation in 2008, in line with impulse-responses we find an increased role of expected inflation and the media for both actual and perceived inflation: While expectations become very important for actual inflation, explaining up to 42% of its forecast error variance in the longer run, both expectations and the media become dominant for perceptions, each explaining almost 30% of its forecast error variance. As the strong effect of perceptions on expectations remains valid also in the extended model, results suggest more interaction between perceived and expected inflation in the extended sample. By contrast, the impact of actual inflation is reduced, however, inflation itself becomes more sensitive to perceptions, expectations and the media. Finally, we find some feedback also between the media and inflation perceptions, as the strong effect of media reports on perceptions is mirrored to some extent by perceptions explaining up to 13% of forecast error variance in *vol_articles*.

5.4.2 Granger Causality

After evaluating the dynamics between actual, perceived and expected inflation as well as the media in the SVEC estimations, we also test for Granger causality between the variables.

Causality tests are conducted in a vector error correction (VECM) framework, which allows to test for both long- and short-run causality between the variables, as in Mosconi

Table 5.8: Forecast Error Variance Decomposition

		1998m1–2007m12			1998m1–2008m12		
	Forecast horizon	1 month	25 months	50 months	1 month	25 months	50 months
π	% due to π	100	68	50	100	34	21
	% due to π^p	0	20	25	0	20	24
	% due to π^e	0	7	19	0	33	42
	% due to $vol\_articles$	0	5	6	0	13	13
π^p	% due to π	5	30	23	5	12	8
	% due to π^p	95	47	40	95	36	34
	% due to π^e	0	15	28	0	25	29
	% due to $vol\_articles$	0	8	9	0	27	29
π^e	% due to π	10	17	15	8	5	3
	% due to π^p	34	38	36	37	28	27
	% due to π^e	56	43	48	55	58	60
	% due to $vol\_articles$	0	2	1	0	9	10
$vol\_articles$	% due to π	1	2	2	0	5	7
	% due to π^p	0	0	0	4	12	13
	% due to π^e	2	3	2	0	5	7
	% due to $vol\_articles$	97	95	96	96	78	73

Note: Forecast error variance decompositions for the 1998m1–2007m12 sample are from the restricted model.

and Giannini (1992) and Kirchgässner and Wolters (2007).[21] Assuming two endogenous variables y_t^1 and y_t^2, the model takes the following form:

$$\begin{pmatrix} \Delta y_t^1 \\ \Delta y_t^2 \end{pmatrix} = \begin{pmatrix} \gamma_1 \\ \gamma_2 \end{pmatrix} \begin{pmatrix} ecm_{t-1} \end{pmatrix} + \sum_{i=1}^{p} \begin{pmatrix} a_i^{11} & a_i^{12} \\ a_i^{21} & a_i^{22} \end{pmatrix} \begin{pmatrix} \Delta y_{t-i}^1 \\ \Delta y_{t-i}^2 \end{pmatrix} + CD_t + \begin{pmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \end{pmatrix}, \tag{5.5}$$

where ecm denotes the long-run cointegration relation, D_t contains deterministic variables and ε_t is the vector of *i.i.d.* error terms. As in Granger (1969), a variable is then said to be Granger-causal for another variable if it contains useful information for predicting that latter variable. In the VECM framework, y_t^2 will be Granger-causal for y_t^1 in the long-run if a Wald test rejects the null hypothesis $H_0 : \gamma_1 = 0$, but not $H_0 : a_1^{12} = ... = a_p^{12} = 0$. Conversely, we find Granger causality in the short-run, if the Wald test rejects $H_0 : a_1^{12} = ... = a_p^{12} = 0$, but not $H_0 : \gamma_1 = 0$. Instantaneous causality between perceived and expected inflation is present if the null hypothesis $H_0 : Cov(\varepsilon_t^1, \varepsilon_t^2) = 0$ can be rejected.

We conduct tests for pairwise Granger causality between perceived and expected inflation, and also tests for block-exogeneity in a larger VECM model including actual, perceived and expected inflation, as well as media reports about inflation. Again, all VECM models are estimated with 2 lags.[22]

Pairwise tests for Granger-causality between perceived and expected inflation, as well as tests for instantaneous causality, are summarized in Table 5.9 for the two sample periods. Results imply that Granger-causality in the period 1998m1–2007m12 runs from inflation expectations to inflation perceptions, both in the short and in the long run. This suggests that in the period of relatively stable inflation rates in Sweden from January 1998 to December 2007, lagged expected inflation provided significant information for predicting perceived inflation, while the reverse was not the case. Nevertheless, the finding of instantaneous causality between perceptions and expectations in all models also indicates some feedback between the variables in the current period.

However, when we extend the sample to include the high inflation year 2008, the pattern of one-way causality from expectations to perceptions breaks down. Rather,

[21] A more general version of Granger causality tests in models with integrated variables conducts the tests in a VAR framework adjusted with one extra lag, see Toda and Yamamoto (1995). While these general tests yield similar results, we present results from the more efficient tests differentiating between long- and short-run causality.

[22] All estimated VECM models satisfy stability criteria and test results find no significant evidence of autocorrelation or heteroscedasticity in the residuals. Test results are available from the author upon request.

Table 5.9: Pairwise Granger Causality between π^e and π^p

1998m1–2007m12	$\pi^e \rightarrow \pi^p$	$\pi^p \rightarrow \pi^e$	$\pi^p \leftrightarrow \pi^e$
Long-run	3.33*	0.06	34.472***
	(0.068)	(0.806)	(0.000)
Short-run	4.60*	4.44	
	(0.100)	(0.109)	
1998m1–2008m12	$\pi^e \rightarrow \pi^p$	$\pi^p \rightarrow \pi^e$	$\pi^p \leftrightarrow \pi^e$
Long-run	5.08**	15.31***	39.584***
	(0.024)	(0.000)	(0.000)
Short-run	2.99	16.62***	
	(0.224)	(0.000)	

Note: χ^2 statistics with p-values in parentheses. *,** and *** denote rejection of H_0 at the 10%, 5% and 1% level, respectively.

we find evidence of reverse causality between perceived and expected inflation in the long run. Furthermore, test results suggest short-run causality from perceptions to expectations. It thus seems that events in 2008 caused inflation perceptions to change before expectations in the short run, while both variables are significantly affected by their long-run cointegration relationship.

Test results for long-run and short-run Granger causality in a larger VECM including π, π^p and π^e as well as different media variables are presented in Tables 5.10 and 5.11.[23] Since all endogenous variables are included in the long-run cointegration relation, tests for long-run Granger causality in Table 5.10 only allow to test for block-exogeneity. However, when testing for short-run Granger causality in Table 5.11, we can distinguish between effects of each variable.

Overall, test results for long-run block-exogeneity for the period 1998m1–2007m12 confirm the weak exogeneity of inflation expectations, as all tests cannot reject the null of no Granger causality from π, π^p and *media* to π^e. With respect to the remaining three variables, we find reverse long-run Granger causality. Extending the sample period to include the high inflation year 2008, results find reverse long-run causality between perceived and expected inflation also when accounting for actual inflation and the media, as all models reject the null of no causality towards π^p and π^e at the 1% level. By

[23]Note that the extended VECM was estimated with cointegration rank two to account for two cointegration relations between actual, perceived and expected inflation.

Table 5.10: Long-Run Granger Causality in the Extended SVEC

1998m1–2007m12	1) *vol_articles*	2) *vol_tone*	3) *vol_tone_subj*	4) *vol_foodenergy*
$\pi^p, \pi^e, media \rightarrow \pi$	6.69**	5.26*	6.81**	6.54**
	(0.035)	(0.072)	(0.033)	(0.038)
$\pi^e, \pi, media \rightarrow \pi^p$	5.84*	6.61**	5.79*	6.45**
	(0.054)	(0.037)	(0.055)	(0.040)
$\pi^p, \pi, media \rightarrow \pi^e$	0.59	1.09	0.36	0.61
	(0.745)	(0.579)	(0.835)	(0.736)
$\pi^p, \pi^e, \pi \rightarrow media$	27.59***	25.37***	21.11***	30.35***
	(0.000)	(0.000)	(0.000)	(0.000)
1998m1–2008m12	1) *vol_articles*	2) *vol_tone*	3) *vol_tone_subj*	4) *vol_foodenergy*
$\pi^p, \pi^e, media \rightarrow \pi$	6.69**	2.48	6.05**	1.19
	(0.035)	(0.289)	(0.049)	(0.550)
$\pi^e, \pi, media \rightarrow \pi^p$	14.03***	21.71***	16.37***	12.46***
	(0.001)	(0.000)	(0.000)	(0.002)
$\pi^p, \pi, media \rightarrow \pi^e$	12.57***	13.87***	13.17***	17.63***
	(0.002)	(0.001)	(0.001)	(0.000)
$\pi^p, \pi^e, \pi \rightarrow media$	5.93*	7.22**	3.96	10.08***
	(0.052)	(0.027)	(0.138)	(0.007)

Note: χ^2 statistics with p-values in parentheses.
*,** and *** denote rejection of H_0 at the 10%, 5% and 1% level, respectively.

Table 5.11: Short-Run Granger Causality in the Extended SVEC

π	1998m1–2007m12	1998m1–2008m12
$\pi^p \rightarrow \pi$	0.37	7.11**
	(0.830)	(0.029)
$\pi^e \rightarrow \pi$	0.82	1.57
	(0.662)	(0.457)
$vol\_articles \rightarrow \pi$	4.84*	3.14
	(0.089)	(0.208)
π^p	1998m1–2007m12	1998m1–2008m12
$\pi^e \rightarrow \pi^p$	3.84	6.05**
	(0.146)	(0.049)
$\pi \rightarrow \pi^p$	0.27	3.81
	(0.873)	(0.149)
$vol\_articles \rightarrow \pi^p$	0.86	6.48**
	(0.651)	(0.039)
π^e	1998m1–2007m12	1998m1–2008m12
$\pi^p \rightarrow \pi^e$	4.44	12.22***
	(0.109)	(0.002)
$\pi \rightarrow \pi^e$	2.01	4.89*
	(0.365)	(0.087)
$vol\_articles \rightarrow \pi^e$	0.90	1.91
	(0.638)	(0.385)
$vol\_articles$	1998m1–2007m12	1998m1–2008m12
$\pi^p \rightarrow vol\_articles$	5.06*	3.33
	(0.080)	(0.189)
$\pi^e \rightarrow vol\_articles$	5.41*	3.37
	(0.067)	(0.186)
$\pi \rightarrow vol\_articles$	0.90	2.09
	(0.639)	(0.352)

Note: χ^2 statistics with p-values in parentheses.
*,** and *** denote rejection of H_0 at the 10%, 5% and 1% level, respectively.

contrast, results regarding long-run Granger causality towards actual inflation and the media are less conclusive and differ across models.

Analyzing tests for short-run Granger causality finally allows to test for the impact of all four endogenous variables separately.[24] Regarding the shorter sample period, we do not find much evidence of short-run Granger causality between the variables, except for some weakly significant effects of the media on actual inflation, and of perceived and expected inflation on the media. By contrast, once the sample period is extended, test results find reverse causality between perceived and expected inflation also in the short run. While perceived inflation becomes predictive for actual inflation rates in the short run, actual inflation is found to affect expectations in addition to perceived inflation, albeit only at the 10% level. In line with results from the SVEC estimations, we additionally find short-run Granger causality from the media to inflation perceptions in the extended sample. This implies that media reports on inflation become useful for predicting perceptions in the short run when accounting for the more turbulent period of high and volatile inflation in 2008.[25]

5.5 Conclusion

Using quantitative survey data for Sweden, we evaluate the formation process of inflation perceptions and expectations as well as interrelations between the variables. In line with the conceptual framework presented in Ranyard et al. (2008), we hypothesize that the media might act as transmission mechanism between perceptions and expectations and, thus, include a number of media variables from a unique data set for Sweden.

After rejecting rationality of both inflation perceptions and expectations, we evaluate their formation process and the role of media reports about inflation. For the low-inflation regime 1998m1–2007m12, we find that in the long run, inflation perceptions are formed on the basis of lagged actual inflation, while expectations are affected by present perceived, not lagged actual, inflation. This result is in line with findings in Maag (2010b), who reports that Swedish households base their inflation expectations

[24] For reasons of space limitation, we present only test results of the model with $vol\_articles$. Results from VECMs with vol_tone, vol_tone_subj and $vol\_foodenergy$ did not differ significantly and are available upon request.

[25] This result is in line with findings in Lamla and Lein (2010) who estimate a LSTAR2 model for perceptions and the media in Germany and find that articles on inflation had a more pronounced effect on inflation perceptions during the time of the Euro cash changeover. As the new currency led to increased uncertainty regarding inflation, it seems that media effects became more powerful, where the authors suggest that the effect was driven by the tone of articles.

largely on perceived, rather than actual, inflation rates. While the media seem to have no significant effect on perceptions in the low-inflation regime, we find some media effects on inflation expectations. Extending the sample period to include the high inflation year 2008, we find more media effects on both expectations and perceptions. Especially inflation perceptions seem to react asymmetrically to negative news, which could be due to loss aversion of households with respect to above-average inflation rates as suggested by Brachinger (2006, 2008) and in our study in chapter 4.

Turning to the analysis of interrelations between actual, perceived and expected inflation, as well as the media, results from an SVEC model imply that in a stable inflation regime, shocks to actual inflation have persistent effects on both perceptions and expectations. While we find a strong effect of a shock to perceptions on expected inflation, the reverse effect builds up more slowly. Overall, media shocks only have small effects. However, when including high inflation in 2008, interaction between perceptions and expectations is found to be stronger, and we find a strong role of media reports working predominantly through a pronounced positive effect on inflation perceptions. While actual inflation becomes more sensitive to changes in perceptions, expectations or the media, its own effect is reduced.

Regarding the direction of causality, pairwise Granger-causality tests suggest causality to run from expectations to perceptions in the short and the long run during the low-inflation period. By contrast, accounting for high and volatile inflation in 2008, Granger-causality tests find reverse long-run causality between perceptions and expectations and additional short-run causality from perceptions to expectations. These results are confirmed when testing for long-run block-exogeneity in a larger model including actual inflation and the media. Moreover, in the extended sample we also find short-run causality from the media to perceptions.

Overall, results for Sweden suggest that in normal times inflation perceptions are less affected by shocks to expectations than the reverse, but past expectations are significant for predicting perceptions both in the long and in the short run. Inflation expectations, on the other hand, are strongly influenced by current perceptions, both in the single-equation and in the SVEC estimations. Interestingly, dynamic SVEC estimations suggest that actual inflation, while important, explains less of the forecast error variance of perceptions and expectations than the variables between themselves. Once inflation becomes higher and more volatile, we find more interaction between inflation perceptions and expectations, as perceptions are increasingly affected by current expectations and become themselves predictive for future expectations in the short run.

Whereas in the low-inflation regime media effects are relatively restricted, they become more important for perceptions and expectations in the extended sample, where especially inflation perceptions increase significantly in response to a rise in media reports on inflation. Furthermore, Granger causality tests find media reports to be predictive for perceptions in the short run. Thus, taking into account the results regarding the cointegration vector in the extended SVEC, we might conclude that media reports indeed become a 'missing link' between perceived and expected inflation when including periods of high and volatile inflation. However, since single-equation results also suggest that perceptions react asymmetrically to media news, their strong impact in the extended sample might have distorting effects on the cointegration relation. For further research it thus remains to be evaluated, whether the dynamics between perceptions and expectations will return to the low-inflation regime once inflation rates have stabilized, or whether they remain altered.

Chapter A

Appendix to Chapter 2

A.1 Mathematical Appendix

A.1.1 Derivation of Optimal Aggregate Consumption

In order to derive optimal aggregate consumption from individual Euler equations, iterate (2.6) forward to get:

$$\begin{aligned} \hat{c}_{t,j} &= \lim_{k\to\infty} E_t^j \hat{c}_{t+k,j} - \frac{1}{\sigma} E_t^j \sum_{k=0}^{\infty} (\hat{i}_{t+k} - \pi_{t+k+1}) \\ &= \hat{c}_\infty^j - \frac{1}{\sigma} E_t^j \sum_{k=0}^{\infty} (\hat{i}_{t+k} - \pi_{t+k+1}) \end{aligned} \tag{A.1}$$

Aggregating across agents with rational and sticky information then gives:

$$\begin{aligned} \hat{c}_t &= \lambda_t \hat{c}_t^{RE} + (1-\lambda_t)\hat{c}_t^{SI} \\ &= \lambda_t \left(\hat{c}_\infty^{RE} - \frac{1}{\sigma} E_t^{RE} \sum_{k=0}^{\infty} (\hat{i}_{t+k} - \pi_{t+k+1}) \right) \\ &+ (1-\lambda_t) \left(\hat{c}_\infty^{SI} - \frac{1}{\sigma} E_t^{SI} \sum_{k=0}^{\infty} (\hat{i}_{t+k} - \pi_{t+k+1}) \right) \\ &= \lambda_t \hat{c}_\infty^{RE} + (1-\lambda_t)\hat{c}_\infty^{SI} - \frac{1}{\sigma} \widetilde{E}_t \sum_{k=0}^{\infty} (\hat{i}_{t+k} - \pi_{t+k+1}), \end{aligned} \tag{A.2}$$

where the last equation makes use of the assumption that the law of iterated expectations holds within and across heterogeneous expectations. Noting that we assume that all agents correctly perceive current nominal interest rates, we then get when extracting expectations for $k = 0$:

$$
\begin{aligned}
\hat{c}_t &= -\frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}) + \lambda_t\hat{c}_\infty^{RE} + (1-\lambda_t)\hat{c}_\infty^{SI} - \frac{1}{\sigma}\widetilde{E}_t\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1}) \\
&= \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}) + \lambda_t\hat{c}_\infty^{RE} + (1-\lambda_t)\hat{c}_\infty^{SI} \\
&- \frac{1}{\sigma}\widetilde{E}_t\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1}) - \widetilde{E}_t\hat{c}_{t+1} \\
&= \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}) + \lambda_t\hat{c}_\infty^{RE} + (1-\lambda_t)\hat{c}_\infty^{SI} - \frac{1}{\sigma}\widetilde{E}_t\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1}) \\
&- \widetilde{E}_t\left(\lambda_{t+1}\hat{c}_\infty^{RE} + (1-\lambda_{t+1})\hat{c}_\infty^{SI} - \frac{1}{\sigma}\widetilde{E}_{t+1}\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1})\right)
\end{aligned} \tag{A.3}
$$

where the last equality substitutes for $\hat{c}_{t+1}$ from equation (A.2). Expanding this expression and exploiting the assumptions regarding the law of iterated expectations across agents and of identical expectations in the limit finally gives the aggregate Euler equation with heterogeneous expectations:

$$
\begin{aligned}
\hat{c}_t &= \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}) + \left[\lambda_t\hat{c}_\infty^{RE} + (1-\lambda_t)\hat{c}_\infty^{SI}\right] \\
&- \left[\widetilde{E}_t\left(\lambda_{t+1}\hat{c}_\infty^{RE} + (1-\lambda_{t+1})\hat{c}_\infty^{SI}\right)\right] \\
&+ \left[(-\frac{1}{\sigma})\widetilde{E}_t\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1})\right] - \left[(-\frac{1}{\sigma})\widetilde{E}_t\widetilde{E}_{t+1}\sum_{k=1}^{\infty}(\hat{i}_{t+k} - \pi_{t+k+1})\right] \\
\hat{c}_t &= \widetilde{E}_t\hat{c}_{t+1} - \frac{1}{\sigma}(\hat{i}_t - \widetilde{E}_t\pi_{t+1}),
\end{aligned} \tag{A.4}
$$

where aggregate heterogeneous expectations $\widetilde{E}_t(x)$ are given by the convex combination of agents with rational and sticky information $\widetilde{E}_t(x) = \lambda_t E_t^{RE}(x) + (1-\lambda_t)E_t^{SI}(x) = \lambda_t E_t(x) + (1-\lambda_t)\overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^j E_{t-1-j}(x)$.

A.1.2 Derivation of the Sticky Information Phillips Curve

Following Ball et al. (2005), the sticky information Phillips curve is derived as follows: Under flexible prices and full information, firms set relative prices equal to real marginal costs and the mark-up $\mu \equiv \frac{\theta}{\theta-1}$:

$$\left(\frac{p^*_{t,i}}{P_t}\right) = \mu\varphi_t = \frac{\theta}{\theta-1}\varphi_t \tag{A.5}$$

Also, the definition of real marginal costs and households' optimal decision regarding the allocation of leisure and the real wage gives:

$$\frac{W_t}{P_t} = \frac{Z_t}{\mu} = \frac{N_t^\eta}{C_t^{-\sigma}}, \tag{A.6}$$

which gives an alternative expression of real marginal costs as $\varphi_t = \frac{C_t^\sigma N_{t,i}^\eta}{Z_t}$. Substituting this expression into (A.5) and assuming market clearing as well as the production function $y_{t,i} = Z_t N_{t,i}$, we get:

$$\left(\frac{p^*_{t,i}}{P_t}\right) = \frac{\theta}{\theta-1}\frac{Y_t^\sigma\left(\frac{y_{t,i}}{Z_t}\right)^\eta}{Z_t} \tag{A.7}$$

Finally, substituting for $y_{t,i}$ with the demand equation in (2.14) and taking logarithms gives:

$$\hat{p}^*_{t,i} = \hat{p}_t + \frac{\sigma+\eta}{1+\eta\theta}\hat{y}_t - \frac{1+\eta}{1+\eta\theta}\hat{z}_t + e_t, \tag{A.8}$$

where again variables with a hat denote deviations from steady state and e_t is an i.i.d. shock that can be interpreted as a cost-push shock resulting, for instance, from wage or tax changes. Now, assuming fully competitive markets with complete information, where all firms set $\hat{p}^*_{t,i} = \hat{p}_t$, we get for the natural output under flexible prices y_t^n:

$$\hat{y}_t^n = \frac{1+\eta}{\sigma+\eta}\hat{z}_t \tag{A.9}$$

Solving (A.9) for $\hat{z}_t$ and substituting into (A.8) then gives the deviation of firm i's optimal price from its steady state in terms of the aggregate price level and the output gap:

$$\hat{p}^*_{t,i} = \hat{p}_t + \frac{\sigma+\eta}{1+\eta\theta}\left(\hat{y}_t - \hat{y}_t^n\right) + e_t \tag{A.10}$$

Accounting for the role of expectations under limited information derived in (2.15), we then get for the aggregate price index:

$$\begin{aligned}\hat{p}_t &= \lambda_t E_t^{RE}\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] + (1-\lambda_t)E_t^{SI}\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] \\ &= \widetilde{E}_t\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] \end{aligned} \tag{A.11}$$

where $\psi = \frac{\sigma+\eta}{1+\eta\theta}$. Note that this again makes use of assumptions regarding heterogeneous expectations, namely the law of iterated expectations and mathematical rules regarding linear expectation operators. Finally, to derive an expression for aggregate inflation, we lag equation (A.11) by one period and subtract it from (A.11), setting $\lambda_t \approx \overline{\lambda}$. Note that this assumption rules out any effect of large changes in the share of rational agents on price changes between two periods. This facilitates the derivation of a Phillips curve with sticky information, where time-variation of the share of rational agents is then re-introduced by allowing a choice between rational and sticky information in period t-1. We thus get:

$$\begin{aligned}\hat{p}_t - \hat{p}_{t-1} &= \widetilde{E}_t\left[\hat{p}_t + \psi\left(\hat{y}_t - \hat{y}_t^n\right) + e_t\right] - \widetilde{E}_{t-1}\left[\hat{p}_{t-1} + \psi\left(\hat{y}_{t-1} - \hat{y}_{t-1}^n\right) + e_{t-1}\right] \\ \pi_t &= \overline{\lambda}\left(\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right) + \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^{j+1}E_{t-1-j}\left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right] \\ &\quad - \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^{j}E_{t-1-j}\left[\hat{p}_{t-1} + \psi\left(\hat{y}_{t-1} - \hat{y}_{t-1}^n\right) + e_{t-1}\right] \\ \pi_t &= \overline{\lambda}\left(\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right) + \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^{j}E_{t-1-j}\left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right] \\ &\quad - \overline{\lambda}\sum_{j=0}^{\infty}(1-\overline{\lambda})^{j}E_{t-1-j}\left[\hat{p}_{t-1} + \psi\left(\hat{y}_{t-1} - \hat{y}_{t-1}^n\right) + e_{t-1}\right] \\ &\quad - \overline{\lambda}^2\sum_{j=0}^{\infty}(1-\overline{\lambda})^{j}E_{t-1-j}\left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right] \end{aligned} \tag{A.12}$$

Multiplying $\hat{p}_t$ in equation (A.11) by $\overline{\lambda}$ and assuming $\lambda_t \approx \overline{\lambda}$ gives an expression for the last summand:

$$\overline{\lambda}\hat{p}_t = \overline{\lambda}^2 \left(\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right) + (1-\overline{\lambda})\overline{\lambda}^2 \sum_{j=0}^{\infty} (1-\overline{\lambda})^j E_{t-1-j} \left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right]$$

$$\frac{\overline{\lambda}}{1-\overline{\lambda}}\hat{p}_t = \frac{\overline{\lambda}^2}{1-\overline{\lambda}} \left(\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right) + \overline{\lambda}^2 \sum_{j=0}^{\infty} (1-\overline{\lambda})^j E_{t-1-j} \left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right]$$

$$\overline{\lambda}^2 \sum_{j=0}^{\infty} (1-\overline{\lambda})^j E_{t-1-j} \left[\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right] = \overline{\lambda}\hat{p}_t - \frac{\overline{\lambda}^2\psi}{1-\overline{\lambda}} \left(\hat{y}_t - \hat{y}_t^n\right) - \frac{\overline{\lambda}^2}{1-\overline{\lambda}} e_t \tag{A.13}$$

Finally, substituting (A.13) into (A.12) and rearranging, we arrive at the sticky-information Phillips curve as in Ball et al. (2005):

$$\begin{aligned}
\pi_t &= \overline{\lambda} \left(\hat{p}_t + \psi(\hat{y}_t - \hat{y}_t^n) + e_t\right) - \overline{\lambda}\hat{p}_t + \frac{\overline{\lambda}^2\psi}{1-\overline{\lambda}} \left(\hat{y}_t - \hat{y}_t^n\right) + \frac{\overline{\lambda}^2}{1-\overline{\lambda}} e_t \\
&\quad + \overline{\lambda} \sum_{j=0}^{\infty} (1-\overline{\lambda})^j E_{t-1-j} \left[\pi_t + \psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right] \\
\pi_t &= \frac{\psi\overline{\lambda}}{1-\overline{\lambda}} (\hat{y}_t - \hat{y}_t^n) + \frac{\overline{\lambda}}{1-\overline{\lambda}} e_t \\
&\quad + \overline{\lambda} \sum_{j=0}^{\infty} (1-\overline{\lambda})^j E_{t-1-j} \left[\pi_t + \psi\Delta(\hat{y}_t - \hat{y}_t^n) + \Delta e_t\right]
\end{aligned} \tag{A.14}$$

A.1.3 Derivation of the Switching Mechanism

Recursive solutions to the infinite sums of past squared forecast errors are derived as follows:

From equation (2.20), we get when inserting the definition of ω_k:

$$\begin{aligned} U_t^{RE} &= -\sum_{k=0}^{\infty}\left[\omega_k(\hat{x}_{t-k} - E_{t-k-1}\hat{x}_{t-k})^2 + K^{RE}\right] \\ &= -\sum_{k=0}^{\infty}\left[(1-\rho)\rho^k(\hat{x}_{t-k} - E_{t-k-1}\hat{x}_{t-k})^2 + K^{RE}\right] \\ &= -(1-\rho)\sum_{k=0}^{\infty}\left[\rho^k(\hat{x}_{t-k} - E_{t-k-1}\hat{x}_{t-k})^2 + K^{RE}\right] \end{aligned} \tag{A.15}$$

Lagging equation (A.15) by one period gives:

$$U_{t-1}^{RE} = -(1-\rho)\sum_{k=0}^{\infty}\left[\rho^k(\hat{x}_{t-k-1} - E_{t-k-2}\hat{x}_{t-k-1})^2 + K^{RE}\right] \tag{A.16}$$

Now, we get when extracting the first term of the infinite sum in (A.15) and using (A.16):

$$\begin{aligned} U_t^{RE} &= -(1-\rho)\sum_{k=0}^{\infty}\left[\rho^{k+1}(\hat{x}_{t-k-1} - E_{t-k-2}\hat{x}_{t-k-1})^2 + K^{RE}\right] \\ &- (1-\rho)\left[(\hat{x}_t - E_{t-1}\hat{x}_t)^2 + K^{RE}\right] \\ U_t^{RE} &= \rho U_{t-1}^{RE} - (1-\rho)\left[(\hat{x}_t - E_{t-1}\hat{x}_t)^2 + K^{RE}\right] \end{aligned} \tag{A.17}$$

Derivations for U_t^{SI} apply in the same manner.

A.2 Calibration Parameters

Table A.1: Parameter Values for Calibration

Parameters		Baseline Model: McCallum (2001)
intertemporal elasticity of substitution	$1/\sigma$	0.4
coefficient of relative risk aversion	σ	2.5
Inverse of Frisch elasticity of labour supply	η	1
elasticity of substitution between goods	θ	35
coefficient on output gap from PC	$\psi = \frac{\sigma+\eta}{1+\eta\theta}$	0.097
weight of inflation target Taylor rule	μ_π	1.5
weight of output Taylor rule	$\mu_{y^{gap}}$	0.5
interest smoothing Taylor rule	μ_i	0.8
AR term IS shock	α_y	0
AR term PC shock	α_π	0
AR term MP shock	α_i	0
AR term technology shock	α_{tech}	0.950
std IS shock	τ_y	0.030
std PC shock	τ_π	0.030
std MP shock	τ_i	0.0017
std technology shock	τ_{tech}	0.007
Calibration of switching parameters:		
initial share of rational output expectations	λ^y	0.5
initial share of rational inflation expectations	λ^π	0.5
intensity of choice (Brock/Hommes 1997)	γ	10000
memory of past forecast errors (De Grauwe 2010)	ρ	0.5

A.3 The Rationality Cost

Table A.2: Rationality Costs

percentage of	mean $U^{SI}_{y,t}$	mean $U^{SI}_{\pi,t}$
100%	0.002500	0.003000
75%	0.001875	0.002250
50%	0.001250	0.001500
25%	0.000625	0.000750
10%	0.000250	0.000300
0%	0.000000	0.000000

Note: Mean values are generated from a simulation of the baseline model over 1000 periods with $\rho = 0$ and $K^{RE} = 0$.

Chapter B

Appendix to Chapter 3

B.1 Calibration Parameters

Table B.1: Parameter Values for Calibration

Parameters		Baseline Model: McCallum (2001)
intertemporal elasticity of substitution	$1/\sigma$	0.4
coefficient of relative risk aversion	σ	2.5
Inverse of Frisch elasticity of labour supply	η	1
elasticity of substitution between goods	θ	35
coefficient on output gap from PC	$\psi = \frac{\sigma+\eta}{1+\eta\theta}$	0.097
weight of inflation target Taylor rule	μ_π	1.5
weight of output Taylor rule	$\mu_{y^{gap}}$	0.5
interest smoothing Taylor rule	μ_i	0.8
AR term IS shock	α_y	0
AR term PC shock	α_π	0
AR term MP shock	α_i	0
AR term technology shock	α_{tech}	0.950
std IS shock	τ_y	0.030
std PC shock	τ_π	0.030 or 0.015
std MP shock	τ_i	0.0017
std technology shock	τ_{tech}	0.007
Calibration of switching parameters:		
initial share of rational output expectations	λ^y	0.5
initial share of rational inflation expectations	λ^π	0.5
intensity of choice (Brock/Hommes 1997)	γ	10000
memory of past forecast errors (De Grauwe 2010)	ρ	0.5
Rationality cost w.r.t. output (50%)	K_y^{RE}	0.0008
Rationality cost w.r.t. inflation (50%)	K_π^{RE}	0.0011 or 0.0005

Chapter C

Appendix to Chapter 4

C.1 Unit Root Tests and Cointegration

Both inflation perceptions and actual inflation rates in our panel are tested for unit roots, where we assess the unit root properties as well as cointegration relations in a panel setting over the period before and after the Euro introduction (1996–2001 and 2002–2008). We apply five different panel unit root tests: The Levin et al. (2002) test assumes a common unit root process over all series in the sample. It estimates proxies for Δy_{it} and y_{it-1} and tests for the null hypothesis $H_0 : \alpha = 1$ in the regression $\Delta y^*_{it} = \alpha y^*_{it-1} + \eta_{it}$, allowing for individual-specific deterministic intercepts. However, it suffers from the restriction that no cross-sectional correlation is allowed and that it can only test for stationarity of all series in the sample. By contrast, the tests by Im et al. (2003), Maddala and Wu (1999) as well as Choi (2001) (Fisher's ADF and PP test) allow for individual unit root processes. They specify individual unit root tests and derive test statistics to test the null hypothesis $H_0 : \alpha_i = 0$, for all i against the alternative that at least one $\alpha_i \neq 0$. While the tests may include individual-specific short-run dynamics and deterministics such as time trends for each panel member, cross-sectional correlation between countries is still not fully accounted for. This may be a relevant issue for actual and perceived inflation rates in a panel of closely related countries, such as the European countries analyzed here. Therefore, we additionally test for panel unit roots with the Pesaran (2007) Cross-Sectionally Augmented Dickey-Fuller (CADF) test. The test computes a t-bar statistic averaging t-statistic values for $H_0 : \alpha_i = 0$ from a standard ADF-regression augmented with lagged and first-differenced values of the cross-sectional mean of the series. All panel unit root tests are calculated with three lags.

The results in Table C.1 mostly reject the null hypothesis of a unit root in perceptions for the period before the Euro cash changeover, where only the Levin et al. (2002) cannot reject the null at the 10% level. However, test results for the post-Euro period generally reject the null of a unit root in perceptions, with the exception of the Pesaran (2007) CADF test. We thus find mixed results with regard to stationarity of perceptions in our sample, where the Pesaran (2007) test indicates that our result of stationarity in the post-Euro period might be biased due to the cross-sectional correlation of perceived inflation rates in the panel. By contrast, evidence of stationarity of inflation rates for both sample periods is relatively convincing: All tests reject the null of a unit root at least at the 10% level, where stationarity of at least some series in the panel is confirmed mostly at the 5% level. Our results are in line with findings in Lein and Maag (2011), who also find that inflation perceptions are more persistent in a similar panel setting.

Generally, empirical evidence on the order of integration of inflation series is mixed, Altissimo et al. (2006) conclude in a survey that empirical findings seem to lean towards stationarity of inflation.

Additionally, we also test for unit roots in the inflation rates of COICOP-price categories, where results are given in Table C.2 and C.3. Again, results are mixed and stationarity is suggested for some COICOP-categories, while it is rejected for others. However, we find more evidence of stationarity in the post-Euro sample, in line with our results regarding inflation perceptions.

Due to the inconclusive evidence on stationarity of inflation in our panel, we furthermore test for panel cointegration between perceived and (aggregate as well as COICOP) actual inflation, see Table C.4. Table C.4 shows seven panel cointegration test statistics proposed by Pedroni (1999, 2001, 2004) that are calculated by extending the Engle-Granger-framework to the panel setting and testing for stationarity of the residual from a regression with I(1) variables, while allowing for individual fixed effects and time trends. The null hypothesis of no cointegration ($\rho_i = 1$) is tested either against the alternative of a common cointegrating vector ($\rho_i = \rho < 1$) or against the alternative of individual cointegrating relationships ($\rho_i < 1$). The Kao (1999) panel cointegration test is also residual-based, but does not allow for individual-specific deterministics. Stationarity of the residuals from the first-stage regression is then tested with a panel ADF test on the null of no cointegration against the alternative of a common cointegrating vector. Finally, the Maddala and Wu (1999) test computes individual Johansen cointegration trace tests and maximum eigenvalue tests and uses those to obtain a combined Fisher statistic. Gutierrez (2003) conducts a Monte Carlo experiment to compare the power of Kao (1999) and Pedroni (1999, 2001, 2004) tests and finds that as T gets large, the Pedroni tests have higher power than the Kao test.

Analyzing the pre-Euro and post-Euro periods, the results suggest a robust cointegration relationship between perceptions and inflation: In the period 1996–2001, most test statistics reject the null of no cointegration at the 1% level with only a few rejecting at the 5%, while in the 2002–2008 period, all panel cointegration tests in Table C.4 reject the null of no cointegration at the 1% level. Thus, there is convincing evidence for panel cointegration between perceived and actual inflation once the structural break of the Euro introduction is accounted for. This result holds both for the alternative of individual cointegration relations and the alternative of a common cointegration vector. Our, quite intuitive, result is in line with findings in Lein and Maag (2011) who also report panel cointegration between perceptions and inflation with a slightly different sample. In addition to panel cointegration tests between perceptions and inflation, we furthermore report results of a Kao (1999) test on cointegration between perceptions and inflation of the 12 COICOP-price aggregates that together form the HICP index. Due to the relatively large number of variables, we could not calculate the other test statistics. Again, the Kao (1999) test rejects the null of no cointegration at the 1% level for both the pre- and post-Euro periods.

Table C.1: Panel Unit Root Tests for Perceptions and Aggregate Inflation

	1996–2001				2002–2008			
	perceptions		inflation		perceptions		inflation	
Method	Statistic	Prob.*	Statistic	Prob.*	Statistic	Prob.*	Statistic	Prob.*
H_1: Stationarity of all series in the panel								
Levin, Lin & Chu t-stat	-1.326	0.093	-2.374	0.009	-2.114	0.017	-1.453	0.073
H_1: Stationarity of some series in the panel								
Im, Pesaran & Shin W-stat	-0.404	0.343	-1.840	0.033	-2.853	0.002	-3.129	0.001
ADF – Fisher Chi-square	20.501	0.427	33.921	0.027	43.065	0.002	43.680	0.002
PP – Fisher Chi-square	23.669	0.257	33.362	0.031	48.542	0.000	44.061	0.002
Pesaran CADF t-bar	-1.929	0.303	-2.435	0.011	-1.551	0.787	-2.171	0.087

* Probabilities for Fisher tests are computed using an asympotic Chi-square distribution.
All other tests assume asymptotic normality.

Table C.2: Panel Unit Root Tests for COICOP-Inflation, pre-Euro 1996–2001

	Levin, Lin & Chu t-stat		Im, Pesaran & Shin W-stat		ADF – Fisher Chi-square		PP – Fisher Chi-square		Pesaran CADF t-bar stat.	
COICOP	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*
cp1	0.250	0.599	0.452	0.674	13.770	0.842	7.542	0.995	-2.339	0.027
cp2	-2.594	0.005	-5.554	0.000	82.238	0.000	27.725	0.116	-2.571	0.003
cp3	-5.892	0.000	-8.531	0.000	139.109	0.000	136.736	0.000	-1.302	0.950
cp4	0.281	0.611	-0.539	0.295	19.881	0.465	17.611	0.613	-1.833	0.428
cp5	1.482	0.931	1.570	0.942	15.391	0.754	17.107	0.646	-1.499	0.833
cp6	1.711	0.957	1.657	0.951	15.785	0.730	13.486	0.856	-0.807	1.000
cp7	0.909	0.818	0.607	0.728	11.357	0.936	12.265	0.907	-1.862	0.389
cp8	-0.742	0.229	-0.858	0.196	20.128	0.450	20.573	0.423	-1.969	0.258
cp9	-0.255	0.400	-0.947	0.172	25.575	0.180	42.152	0.003	-1.630	0.697
cp10	0.132	0.553	0.433	0.668	19.376	0.498	21.930	0.344	2.355	0.991
cp11	-0.129	0.449	-1.143	0.127	42.714	0.002	57.476	0.000	-0.890	0.999
cp12	1.038	0.850	2.264	0.988	7.291	0.996	7.744	0.993	-2.260	0.049

* Probabilities for Fisher tests are computed using an asympotic Chi-square distribution.
All other tests assume asymptotic normality.

Table C.3: Panel Unit Root Tests for COICOP-Inflation, post-Euro 2002–2008

	Levin, Lin & Chu t-stat		Im, Pesaran & Shin W-stat		ADF – Fisher Chi-square		PP – Fisher Chi-square		Pesaran CADF t-bar stat.	
COICOP	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*	Stat.	Prob.*
cp1	0.010	0.504	-1.491	0.068	31.343	0.051	28.602	0.096	-1.833	0.427
cp2	-2.142	0.016	-4.421	0.000	56.421	0.000	54.837	0.000	-2.499	0.006
cp3	-7.685	0.000	-9.337	0.000	136.527	0.000	183.468	0.000	-1.744	0.549
cp4	-1.312	0.095	-2.427	0.008	34.292	0.024	32.439	0.039	-2.044	0.179
cp5	-2.178	0.015	-2.171	0.015	39.629	0.006	53.195	0.000	-2.470	0.008
cp6	-0.571	0.284	-2.457	0.007	39.358	0.006	40.565	0.004	-2.540	0.004
cp7	-0.945	0.172	-5.176	0.000	64.606	0.000	50.169	0.000	-2.014	0.208
cp8	-0.861	0.195	-1.666	0.048	25.912	0.169	25.351	0.188	-1.854	0.398
cp9	-2.645	0.004	-2.719	0.003	36.602	0.013	56.947	0.000	-2.093	0.138
cp10	-1.044	0.148	-2.452	0.007	32.860	0.035	39.361	0.006	-2.813	0.000
cp11	-0.186	0.426	-0.752	0.226	20.573	0.423	32.468	0.039	-1.942	0.287
cp12	-0.681	0.248	-1.662	0.048	27.456	0.123	31.205	0.053	-2.300	0.035

* Probabilities for Fisher tests are computed using an asympotic Chi-square distribution.
All other tests assume asymptotic normality.

Table C.4: Panel Cointegration Tests between Perceptions and HICP/COICOP Inflation

Method		1996–2001		2002–2008	
Pedroni Tests		Weighted Stat.	Prob.	Weighted Stat.	Prob.
Alternative hypothesis: common AR coefs.					
Panel v-Statistic		2.357	0.009	5.890	0.000
Panel rho-Statistic		-4.764	0.000	-6.818	0.000
Panel PP-Statistic		-4.122	0.000	-5.932	0.000
Panel ADF-Statistic		-3.478	0.000	-4.230	0.000
		Stat.	Prob.	Stat.	Prob.
Alternative hypothesis: individual AR coefs.					
Group rho-Statistic		-4.584	0.000	-5.345	0.000
Group PP-Statistic		-4.479	0.000	-6.116	0.000
Group ADF-Statistic		-3.673	0.000	-4.220	0.000
Kao ADF Test					
		t-Stat.	Prob.	t-Stat.	Prob.
		-3.667	0.000	-4.452	0.000
Maddala & Wu Test					
		Fisher-Stat.*	Prob.	Fisher-Stat.*	Prob.
Trace test	None	55.420	0.000	87.440	0.000
	At most 1	34.920	0.021	74.140	0.000
Max.-Eigenvalue test	None	50.360	0.000	59.120	0.000
	At most 1	34.920	0.021	74.140	0.000
Cointegration between Perceptions and COICOP-Inflation:					
Kao ADF Test					
		t-Stat.	Prob.	t-Stat.	Prob.
		-5.057	0.000	-5.243	0.000

* Probabilities for Fisher tests are computed using an asympotic Chi-square distribution.
All other tests assume asymptotic normality.

C.2 Structural Break Tests

Table C.5: Quandt-Likelihood-Ratio Test for Structural Breaks I

	Loss Aversion Model with Threshold 1			Loss Aversion Model with Threshold 2		
	Max. Wald F	p-value	Date	Max. Wald F	p-value	Date
at	153.670	<0.001	2002M02	160.916	<0.001	2002M02
be	182.587	<0.001	2002M04	161.003	<0.001	2002M04
es	284.427	<0.001	2002M05	243.092	<0.001	2002M05
fi	93.991	<0.001	2002M02	127.207	<0.001	2002M02
fr	270.878	<0.001	2001M08	169.536	<0.001	2001M08
ger	25.488	<0.001	2001M05	16.045	0.0205	2000M09
gr	465.868	<0.001	2002M09	482.446	<0.001	2002M09
it	95.775	<0.001	2002M06	80.281	<0.001	2002M06
nl	71.422	<0.001	2002M05	64.198	<0.001	2002M05
pt	62.233	<0.001	2002M05	100.184	<0.001	2002M05

Table C.6: Quandt-Likelihood-Ratio Test for Structural Breaks II

	Availability Model		
	Max. Wald F	p-value	Date
at	43.233	<0.001	2002M02
be	29.170	0.1023	2002M09
es	30.747	0.0674	2002M06
fi	16.447	0.8782	2002M02
fr	7.241	1.0000	2002M05
ger	12.524	0.9923	2003M09
gr	53.423	<0.001	2002M04
it	28.398	0.1243	2002M06
nl	27.386	0.159	2002M04
pt	20.703	0.5725	2003M02

C.3 Definition of COICOP Categories

Table C.7: Definition of Frequently Bought Goods Categories

COICOP definition		percentage included in FROOPP Index
cp1	Food and non-alcoholic beverages	100%
cp2	Alcoholic beverages, tobacco and narcotics	100%
cp3	Clothing and footwear	2.2%
cp4	Housing, water, electricity, gas and other fuels	0%
cp5	Furnishings, household equip. and maintenance	25.9%
cp6	Health	32.4%
cp7	Transport	42.7%
cp8	Communications	4.5%
cp9	Recreation and culture	50.5%
cp10	Education	0%
cp11	Restaurants and hotels	82.7%
cp12	Miscellaneous goods and services	33.6%

Chapter D

Appendix to Chapter 5

D.1 Unit Root Tests and Cointegration

Apart from the standard augmented Dickey-Fuller (ADF) test for a unit root developed by Dickey and Fuller (1979), we also conduct a GLS-detrended version of the Dickey-Fuller test (DF GLS) proposed in Elliott et al. (1996) and the Phillips and Perron (1988) (PP) test for a unit root. Additionally, Table D.1 reports values of the Kwiatkowski et al. (1992) (KPSS) test that tests for the null hypothesis of stationarity as opposed to the null of a unit root. All test regressions are estimated with a constant, but excluding a linear trend. Approximate p-values for the ADF and PP test statistics are from MacKinnon (1994).

The ADF test of Dickey and Fuller (1979) tests for the null hypothesis of a unit root by estimating the regression

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta + \beta_1 \Delta y_{t-2} + ... + \beta_p \Delta y_{t-p} + \epsilon_t, \tag{D.1}$$

where x_t denotes a vector of exogenous variables that may include a constant and a linear time-trend. The null hypothesis of a unit root is then tested as $H_0 : \alpha = 0$ against the alternative $H_1 : \alpha < 0$. The DF GLS test from Elliott et al. (1996) estimates the ADF test statistic in equation (D.1) using data that have been detrended by substracting $x_t'\hat{\delta}$, where $\hat{\delta}$ is the coefficient of a GLS estimation of Δy_t on Δx_t. Phillips and Perron (1988) use the standard Dickey-Fuller test regression excluding additional lagged differences of y_t and control for autocorrelation by using Newey-West standard errors when calculating the test statistic. The Kwiatkowski et al. (1992) KPSS test analyzes the reversed null of (trend) stationarity by regressing the variable in question on a constant (and a time trend) and testing for stationarity of the partial sums of the residuals, which under the null should be integrated of order one.

From Table D.1, we see that all tests reject the null hypothesis of a unit root in the media variable *vol_articles* (i.e. cannot reject the null of stationarity), where the same result of stationarity applies to all other media variables. With respect to actual, perceived and expected inflation, results are less clear-cut: In the case of actual inflation π, both the ADF and the DF GLS test cannot reject the null of a unit root, while the PP test rejects at the 10% level and the KPSS test cannot reject the null of stationarity at the 5% level. For perceived inflation π^p, all unit root tests fail to reject the null of a unit root, while the KPSS test rejects the null of stationarity at the 5% level. Finally, both the ADF and the PP test suggest inflation expectations π^e to be stationary, as the null hypothesis is rejected at the 5% level. However, the DF GLS test cannot reject at this significance level and also the KPSS test rejects the null of stationarity at the

5% level. Thus, there is some evidence of non-stationarity for actual, perceived and expected inflation during the time span analyzed here.

Hence, we proceed to estimate Johansen (1991, 1995) tests of cointegration between the variables. The tests are conducted in the framework of a vector error correction model (VECM) of the form

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + B x_t + \epsilon_t, \tag{D.2}$$

where y_t is a k-vector of nonstationary endogenous variables, x_t is a vector of exogenous variables and Π, Γ_i and B are coefficient matrices. Granger's representation theorem then states that if the coefficient matrix Π has reduced rank $r < k$, then there exist r cointegration relations between the variables in y_t such that $\Pi = \alpha\beta'$ and each column in β represents a cointegrating vector.

Table D.2 presents both trace statistics and maximum eigenvalue statistics of the Johansen (1991, 1995) cointegration tests for bivariate cointegration between the pairs (π^e, π^p), (π, π^e) and (π, π^p) as well as tests for trivariate cointegration between (π, π^e, π^p). All tests for bivariate cointegration reject the null hypothesis of no cointegration (rank 0) at the 1% level, but show much smaller test statistics when testing for the null of 1 cointegration relationship (rank 1). Although the test statistic is still above the 5% critical value, the tests nevertheless indicate the existence of a cointegration relationship between the variables. Similarly, when testing for cointegration in the trivariate VECM including actual, perceived and expected inflation, we find evidence of two cointegrating relations between the variables. We thus conclude that while there is some evidence of non-stationarity regarding actual, perceived and expected inflation, it seems that all three variables are cointegrated. This result is in line with findings in Lein and Maag (2011) and in the previous chapter 4, where we find evidence of panel-cointegration between actual and perceived inflation for European samples. For the empirical analysis, estimations are hence done either in levels, specifying long-run relationships, or in the framework of error correction models.

Table D.1: Unit Root Tests

		π	π^e	π^p	$vol\_articles$
ADF test	Test stat.	-2.476	-3.321	-1.984	-7.399
	Approx. p-value	0.121	0.014	0.294	0.000
	Lags	1	1	1	1
DF GLS test	Test stat.	-1.576	-1.962	-1.970	-2.617
	5% crit. value	-1.972	-2.020	-2.041	-2.596
	Lags	12	6	3	2
PP test	Test stat.	-2.750	-3.151	-2.003	-7.815
	Approx. p-value	0.066	0.023	0.285	0.000
	Lags	1	1	1	1
KPSS test	Test stat.	.246	.674	.723	.257
	5% crit. value	0.463	0.463	0.463	0.463
	Lags	12	12	12	12

Note: Approximate p-values are from MacKinnon (1994).

Table D.2: Johansen Cointegration Tests

		π^e, π^p	π, π^e	π, π^p	π, π^e, π^p
trace stat.	rank 0	27.255***	23.955***	23.148***	44.930***
	rank 1	5.436**	6.600**	4.245**	22.805***
	rank 2	-	-	-	6.162**
max. eigenvalue stat.	rank 0	21.819***	17.355***	18.903***	22.125***
	rank 1	5.436**	6.600**	4.245**	16.643***
	rank 2	-	-	-	6.162**

Note: *** and ** denote rejection of H0 at the 1% and 5% level, respectively.

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