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Non-Technical Summary

Simple instrument rules like a Taylor rule that link the policy rate to inflation and measures of economic activity are widely used concepts in monetary macroeconomics. Even though the idea is simple, Taylor rules have been used in various areas for both positive and normative analyses. On the one hand, as Taylor himself originally pointed out, such a rule is able to explain U.S. monetary policy extraordinarily well. This finding has frequently been captured and confirmed. On the other hand, Taylor rules can be used in order to ex-post evaluate monetary policy and assess the quality of the monetary policy stance by comparing actual developments in the policy rate with the interest rate implied by the Taylor rule. In other words, policy is said to be too loose when the monetary policy instrument was below the Taylor rule-implied interest rate, whereas it is said to be too tight if it was above the implied rate.

There is evidence that Taylor rules also have some value in evaluating the quality of monetary policy, or, put differently, it provides information about what a “good” action for a monetary authority might be. In this respect, public statements from policy makers strongly suggest that central banks around the globe indeed let the information resulting from simple instrument rules influence their policy choice or, at least, use resulting information as cross-checks for their decisions.

We examine whether cross-checking policy rate decisions with information from simple instrument rules under model uncertainty documented in previous research carries over to the case of parameter uncertainty. In other words, we consider a form of uncertainty where the monetary authority is to a certain degree confident about the true economic environment. We find that adjusting monetary policy based on this kind of cross-checking can be beneficial for the monetary authority. This, however, crucially depends on the importance that the monetary authority attaches to stabilizing output volatility relative to stabilizing inflation volatility as well as the degree of monetary policy commitment. The monetary authority is on average able to benefit from policy rate cross-checking when it only moderately cares about stabilizing output and when policy is set in a discretionary way.

Optimal policy and Taylor rule cross-checking under parameter uncertainty*

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Abstract

We examine whether the robustifying nature of Taylor rule cross-checking under model uncertainty carries over to the case of parameter uncertainty. Adjusting monetary policy based on this kind of cross-checking can improve the outcome for the monetary authority. This, however, crucially depends on the relative welfare weight that is attached to the output gap and also the degree of monetary policy commitment. We find that Taylor rule cross-checking is on average able to improve losses when the monetary authority only moderately cares about output stabilization and when policy is set in a discretionary way.
Keywords: Optimal monetary policy, parameter uncertainty, Taylor rule. *JEL-Classification:* E47, E52, E58.

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1 Introduction

The Taylor rule is a widely used concept in monetary macroeconomics. Even though the idea is simple, it has been used in various areas. Taylor (1993) employs a *positive* analysis in the sense that he points out that the rule explains U.S. monetary policy extraordinarily well. Subsequently, this finding has been frequently captured and confirmed. Gerlach and Schnabel (2000) apply the concept to pre-European Monetary Union data and estimate a policy rule for euro area countries. They show that monetary policy can also be described well by a Taylor rule and obtain similar coefficient estimates as the ones initially assumed by Taylor (1993). Other studies suggest that using real time data and projections for estimating the policy rule parameters might even improve the explanatory power of the Taylor rule (Orphanides and Wieland, 2008).

On the other hand, Taylor rules can be used in order to ex-post evaluate monetary policy and therefore to employ a *normative* analysis. The quality of monetary policy can be assessed by comparing actual developments in the short term interest rate with the interest rate implied by a Taylor rule, in other words policy was too loose when the monetary policy instrument was below the Taylor rule-implied interest rate, whereas it was too tight if it was above the implied rate. Poole (2007) defines monetary policy following the Taylor rule as being "systematic", hence he is able to find periods where U.S. monetary policy is not systematic according to his definition.

Selected statements from either policy makers or academics furthermore suggest that interest rates based on the Taylor rule provide information whether or not the current monetary policy stance is adequate. Governor Janet Yellen indicated the Taylor rule as a means of providing her "a rough sense of whether or not the funds rate is at a reasonable level". "I do not disagree with the Greenbook strategy. But the Taylor rule and other rules ... call for a rate in the 5 percent range, which is where we already are. Therefore, I am not imagining another 150 basis points." (FOMC transcripts, January 31 to February 1, 1995). Among others, Taylor and Williams (2010) argue that "simple monetary policy rules are designed to take account of only the most basic principle of monetary policy of leaning against the wind of inflation and output movements. Because they are not fine tuned to specific assumptions, they are more robust to mistaken assumptions."

We investigate the usefulness of the Taylor rule for monetary policy as a "guideline" in the sense that it provides valuable information for the monetary authority about the adequateness of its monetary policy. More precisely, we examine the usefulness of "Taylor rule cross-checking", namely whether deviations of the Taylor rule-implied interest rate from the interest rate resulting from an optimization problem of the monetary authority should influence policy rate decisions. The contribution of the paper is twofold. First, we consider the case where the monetary authority is only faced with uncertainty on the side of the parameters of the data generating process[1] due to, for instance, insufficient estimation techniques, rather than the entire transmission mechanism itself as analyzed in Ilbas et al. (2012). Hence, we consider certainty with respect to the structure of the economy but parameters are assumed to be unknown and remain constant over time which clearly influences the effectiveness of policy actions. Second, we investigate to what extent the effectiveness of cross-checking is influenced by the monetary authority's type reflected by the relative weight it attaches to output stabilization and also the degree of monetary policy commitment. In order to address the latter question, we also consider monetary policy under discretion which has not been examined in this context before. We perform multiple simulations of a Smets and Wouters (2003) economy using an augmented monetary authority's objective function and different realizations of the random shock processes. Hence, our simulations provide us with a whole distribution of the monetary authority's objective.

We find that Taylor-rule cross-checking can on average improve the monetary authority's losses when it only moderately cares about stabilizing output relative to stabilizing inflation and when policy is set in a discretionary way. In other words, policy makers which are less concerned about economic activity and those who cannot credibly commit to an announced policy in

[1] See, for instance, Tillmann (2011), Giannoni (2007), or Söderström (2002) for other approaches on parameter uncertainty.

general benefit more from Taylor rule cross-checking. Attention should be paid to choosing the appropriate relative weight λ_Δ which is attached to the information resulting from Taylor rule cross-checking.

The paper is broadly related to the literature that examines the usefulness of the Taylor rule for the conduct of monetary policy. As the Taylor rule seems to provide information about what a "good" action for a monetary authority might be, empirical studies examine the responsiveness of the interest rate to developments in the inflation rate. Judd and Rudebusch (1998) look at monetary policy of different Federal Reserve chairmen in terms of estimated policy reaction functions. The Burns chairmanship, for example, is identified as being less responsive to inflation which is put forward as a reason for high realized inflation during the same time period. Furthermore, Tillmann (2012) illustrates the usefulness of simple instrument rules by showing that cross-checking optimal monetary policy under discretion with information from the Taylor rule reduces the stabilization bias in a small scale dynamic stochastic general equilibrium (DSGE) model. Ilbas et al. (2012) show in a different setting that the Taylor rule can robustify monetary policy in case of model uncertainty, in other words in the case of a complete mismatch between the model that the monetary authority uses in order to determine its monetary policy and the true model and therefore the data generating process of the economy. They find that in such a framework, even putting a small weight on the information resulting from Taylor rule cross-checking in the process of the determination of optimal monetary policy is able to insure against bad outcomes.[2] In an empirical exercise, they argue that actual monetary policy may be described by optimal monetary policy which incorporates cross-checking of this kind. Other approaches on cross-checking are discussed, for instance, in Beck and Wieland (2008) and Christiano and Rostagno (2001). Their approaches can be seen as alternatives to the robust policy proposed by Hansen and Sargent (2008) which is discussed for DSGE models in Giordani and Söderlind (2004) where the monetary authority also has a reference model at hand and considers the

[2] See, for instance, Levin et al. (2003), Levin and Williams (2003), or Levin et al. (1999) for other approaches on optimal monetary policy under model uncertainty.

possibility of a bad shock hitting the model economy.

The remainder of this paper is organized as follows. Section 2 comments on the theoretical framework including the conduct of monetary policy and the model economy while section 3 presents simulation setup and simulation results. The conclusion follows.

2 The theoretical framework

2.1 The conduct of monetary policy

In most cases, a Taylor-type rule is specified in order to close a DSGE model where the nominal interest rate is a function of inflation and some measure of economic activity. However, in our case, this step is obsolete. Our aim is to replace an ad hoc and exogenously specified policy rule by a policy rule that is obtained from the optimization problem of the monetary authority. We assume that the monetary policy objective can be summarized by a simple quadratic loss function. That is to say that the monetary authority minimizes the weighted sum of the variances of certain target variables. This approach is standard and for example presented in Clarida et al. (1999). However, note that this loss function is not derived from welfare-theoretical considerations. On the contrary, it is an ad hoc objective function trying to describe preferences of the monetary authority. One could also think of this loss function as a way to model flexible inflation targeting as introduced by Svensson (1999) where the monetary authority seeks to stabilize inflation, output, and potentially other target variables simultaneously. We define the "traditional" per period loss function as

$$L_t \equiv \hat{\pi}_t^2 + \lambda_y \hat{y}_t^2, \tag{1}$$

where the parameter λ_y captures the relative importance of stabilizing output, $\hat{y}_t$, to stabilizing inflation, $\hat{\pi}_t$. Variables with circumflex denote log-deviations from the steady-state.

Motivated by the statements about the usefulness of the Taylor rule quoted in the introduction, we argue that equation (1) does not capture the actual objective of the monetary authority. More precisely, the "traditional" per period loss function does not incorporate deviations of the interest rate implied by optimal monetary policy from the interest rate implied by a Taylor-type rule. Hence, in the standard approach, such interest rate deviations are considered irrelevant for the conduct of monetary policy. However, previous research suggests that the monetary authority might be better off following a Taylor-type rule. In the case of uncertainty, the monetary authority may want to insure itself against model misspecification, meaning that it seeks to robustify its policy. Ilbas et al. (2012) show that the Taylor rule can indeed robustify monetary policy in case of model uncertainty, in other words in the case of a complete mismatch between the model that the monetary authority uses in order to determine its monetary policy and the true data generating process of the economy.

We assume that there are two types of models. The first model is referred to as the *reference model* of the monetary authority which reflects its belief of how the economy is structured and what the model parameters are. In principal, the reference model may or may not entirely reflect the data generating process of the economy. This gives rise to the second type of model, which we call the *true model* or the *data generating process*. This model describes the true structure of the economy and may differ from the reference model. In fact, we assume that both the reference model and the true model are structurally identical and therefore reflect the same monetary policy transmission mechanism. However, there is a misspecification on the side of the model parameters as the monetary authority is not able to perfectly estimate all of them. This approach is realistic in the sense that we do not believe the monetary authority (at least in the long run) to get it wrong in terms of the reference model which is the basic implication of Ilbas et al. (2012). Hence, the true model lies in the neighborhood of the monetary authority's reference model and we let the monetary authority optimize using the correct structural model.

The monetary authority uses the reference model and knows about its biased view of the world. It is therefore crucial to note that the policy based on the reference model is "optimal" just precisely in this model. In case of parameter misspecification the policy may very well turn out to be suboptimal and it is difficult to judge ex ante, what the quantitative consequences of a mismatch between the monetary authority's reference model and the data generating process in terms of loss will be. Hence, it might be beneficial to find some way to insure against those misspecification as the exact type of the misspecification is assumed to be unknown.

In what follows, we do not argue that the monetary authority should completely and mechanically follow the Taylor rule in setting the interest rate. Still, the monetary authority should be able to adjust its monetary policy according to the signals it receives from performing Taylor rule cross-checking. Therefore, we redefine its objective by an augmented loss function $\tilde{L}_t$. Consider that the monetary authority also reacts to deviations of the policy instrument from the Taylor rule-implied interest rate. We define this spread as

$$\Delta_t \equiv \hat{i}_t - \hat{i}_t^{TR}, \tag{2}$$

where $\hat{i}_t^{TR}$ denotes the interest rate implied by the Taylor rule. The specific form we use is standard and reads

$$\hat{i}_t^{TR} \equiv \phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t. \tag{3}$$

Inspired by Ilbas et al. (2012), we augment the standard loss function (1) by a cross-checking term representing the squared interest rate spread and a corresponding weighting parameter λ_Δ. Hence,

$$\tilde{L}_t \equiv \hat{\pi}_t^2 + \lambda_y \hat{y}_t^2 + \lambda_\Delta \Delta_t^2. \tag{4}$$

Equation (4) belongs to the class of "modified" loss functions, with the most well-known examples presented in Rogoff (1985) and Walsh (1995).

It is worthwhile to point out that we do not focus on maximizing welfare with respect to the choice of the Taylor-rule parameters in (3). In contrast, our concern is the monetary authority's choice of λ_Δ and its impact on wel-

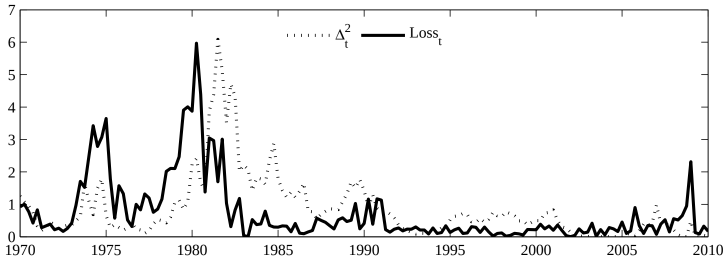

Figure 1: Losses and squared deviations between the federal funds rate and the Taylor rule-implied interest rate for the U.S. .

fare. Hence, we calibrate the Taylor-rule parameters as originally done in Taylor (1993), in other words $\phi_\pi = 1.5$ and $\phi_y = 0.5$. In order to empirically motivate this approach, consider figure 1 where we plot the squared value of Δ_t against the loss resulting from the period loss function (1). We compute those series from actual quarterly U.S. data. For the sake of simplicity, the output gap refers to a Hodrick-Prescott filter de-trended time series. A standard smoothing parameter of 1,600 was applied. A constant inflation target of zero was assumed.[3] The figure suggests that there is a relationship between the monetary authority's loss and deviations of the federal funds rate from the Taylor rule-implied interest rate. Both series are positively correlated. Therefore, it seems that the monetary authority experiences higher losses when deviations of the policy instrument from the Taylor rule-implied interest rate are large and vice versa.

Since the monetary authority faces a dynamic problem, it minimizes a discounted "lifetime" loss function

$$\mathscr{L}_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} (1-\beta)\beta^t \tilde{L}_t, \tag{5}$$

where $0 < \beta < 1$ is the discount factor subject to the equations characterizing the reference model. The standard approach of flexible inflation targeting is nested by setting $\lambda_\Delta = 0$ in (4). Under commitment the monetary authority

[3] Assuming a moderate inflation target of 1 percent and excluding the recent financial crisis starting August 2007 (see, for instance, Trichet, 2010) do not affect the results.

is able to credibly convince the public that it will stick to a particular policy, and thus, it can influence the agents' expectations. This enables the monetary authority, compared to a discretionary policy maker, to obtain lower future losses at the cost of higher losses today. The commitment case is useful in order to isolate the effects of Taylor rule cross-checking from that of lack of credibility and makes results comparable to Ilbas et al. (2012) where a commitment technology is available to the monetary authority. We additionally consider the discretionary case and employ numerical approaches in order to calculate both optimal policies. In particular, we follow Svensson (2010), who also shows how to solve a linear quadratic regulator (LQR) problem with rational expectations.[4]

Let the linear dynamic model equations be

$$\begin{bmatrix} \hat{X}_{t+1} \\ H\hat{x}_{t+1|t} \end{bmatrix} = A \begin{bmatrix} \hat{X}_t \\ \hat{x}_t \end{bmatrix} + B\hat{i}_t + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1}, \tag{6}$$

where $\hat{X}_t$ is an $(n_X \times 1)$-vector of predetermined variables, $\hat{x}_t$ is an $(n_x \times 1)$-vector of non-predetermined variables, ε_{t+1} is an $(n_\varepsilon \times 1)$-vector of i.i.d. shocks with mean zero, and $\hat{x}_{t+1|t}$ is the expectation of $\hat{x}_{t+1}$ conditional on information available at time t.

Minimizing the loss function (5) subject to the linear dynamic model equations (6) under commitment with respect to $\hat{X}_t$, $\hat{x}_t$, and $\hat{i}_t$ yields $n_X + n_x + 1$ first-order conditions. In order to implement a policy which is optimal in a certain model with one parameter set into a different potentially misspecified model, the first-order condition of the Lagrangian with respect to the interest rate $\hat{i}_t$ is replaced by the policy resulting from the optimization problem of the monetary authority. In contrast, implementing optimal discretionary policy only involves replacing an ad hoc policy rule.

[4]Dennis (2007), Dennis (2004), or Söderlind (1999) suggest alternative solution methods to the LQR problem which are equivalent to the method in Svensson (2010).

Parameter	Description	Value	
β	discount factor	0.999	
τ	depreciation rate of capital	0.025	
α	capital output ratio	0.300	
λ_w	markup in wage setting	0.500	
h	habit portion of past consumption	0.573	$*$
ξ_w	Calvo wage stickiness	0.737	$*$
ξ_p	Calvo price stickiness	0.908	$*$
γ_w	degree of partial indexation wages	0.763	$*$
γ_p	degree of partial indexation prices	0.469	$*$
$1/\varphi$	investment adj. cost	6.771	$*$
σ_c	coeff. of relative risk aversion	1.353	$*$
σ_l	inverse elasticity of labor supply	2.400	$*$
ϕ	1+ share of fixed cost in prod.	1.408	$*$
$1/\psi$	elasticity of cap. util. cost	0.169	$*$
inv_y	investment share of GDP	8.8τ	
c_y	consumption share of GDP	$1 - 0.18 - inv_y$	
$\bar{r}_k$	steady-state return on capital	$1/\beta - 1 + \tau$	

Table 1: Calibrated model parameters. Parameters marked with "$*$" are considered for misspecification.

2.2 The model economy

In order to determine optimal monetary policy on the basis of the reference model and to simulate data using the true model, we use a standard DSGE model incorporating sticky wages and prices. The linearized model we employ is closely related to the one developed by Smets and Wouters (2003). Hence, we use a model that is on the one hand accepted in the profession, and on the other hand captures the most relevant frictions necessary to fit actual data. Our calibration can be found in tables 1 and 2 and mostly follows the results in Smets and Wouters (2003) for their estimated euro area model. In what follows, we will just give a brief and non-technical overview of the model features.[5] We focus on the general structure of the model commenting on the frictions implemented.

[5]For readers interested in details of the model and the linearized model equations, we recommend to consult Smets and Wouters (2003).

Parameter	Description	Value	
ρ_{ϵ_a}	AR for productivity shock	0.823	*
ρ_{ϵ_b}	AR for preference shock	0.855	*
ρ_{ϵ_g}	AR for government expenditure shock	0.949	*
ρ_{ϵ_l}	AR for labor supply shock	0.889	*
$\rho_{\epsilon_{inv}}$	AR for investment shock	0.927	*
σ_{ϵ_l}	S.D. of labor supply shock	3.520	
σ_{ϵ_a}	S.D. of productivity shock	0.598	
σ_{ϵ_b}	S.D. of preference shock	0.336	
σ_g	S.D. of government expenditures shock	0.325	
σ_π	S.D. of inflation objective shock	0.017	
$\sigma_{\epsilon_{inv}}$	S.D. of investment shock	0.085	
σ_{λ_p}	S.D. of price markup shock	0.160	
σ_{λ_w}	S.D. of wage markup shock	0.289	
σ_{ϵ_q}	S.D. of equity premium shock	0.604	

Table 2: Calibrated shock processes. Parameters marked with "$*$" are considered for misspecification.

The economy is inhabited by a continuum of households who maximize their expected lifetime utility. Those households decide upon their intertemporal allocation of consumption and are subject to external habit formation meaning that today's utility depends not only on today's consumption but also on last period's aggregate consumption. Technically, consumption habits work as if one assumed consumption adjustment cost, thus they induce consumers to adjust consumption levels more gradually. According to Abel (1990), this effect is sometimes referred to as "catching up with the Joneses", capturing the idea that households compare their consumption level to the one of neighboring households'. Furthermore, they intratemporally face a labor/leisure decision. A shock to the discount factor as well as a shock to preferences are added to the households' optimization problem. Households face a budget constraint which allows them to shift funds intertemporally via riskless bonds and have labor income, income from investment into state-contingent securities, and income from capital investments. Note that a variable capital utilization rate is assumed which in turn affects households' return on capital and improves upon the persistence of the variables in sticky prices general equilibrium models (Dotsey and King, 2006). Therefore, it might be preferable to first increase the utilization rate before extending the existing capital stock.

Wages are set in a staggered way following Erceg et al. (2000). With a fixed and exogenous probability $1 - \xi_w$ wages can be reoptimized whereas with the converse probability, wages cannot be adjusted. As a result, wages are set in a forward looking manner such that future expectations of wages also become relevant for current wages. It is assumed that those wages which cannot be reoptimized are subject to partial indexation which makes current wages also depend on past wages.

On the one hand, households decide about their investment into the capital stock. This investment will be available for production with a one-period lag. On the other hand, households influence the capital utilization rate which determines how intensively the existing capital stock is used. This is of particular importance as households face capital adjustment costs that induce a wedge between the marginal product of capital and its rental rate, introducing a variable price for capital.

The production sector consists of final and intermediate goods producers. Final goods producers construct consumption goods using intermediate goods and sell them to households. Furthermore, they are subject to cost-push shocks. The intermediate goods sector uses utilized capital and labor for production. In order to motivate price setting on the side of the firms, they act under monopolistic competition. Hence, firms have some degree of market power. Prices are set according to Calvo (1983), in other words, firms are able to reoptimize prices with a fixed and exogenous probability $1 - \xi_p$ whereas the non-optimized prices are partially indexed to last period's inflation. This induces price setting to be forward and backward looking at the same time which results in a hybrid version of the New Keynesian Phillips curve.

As indicated before, we do not adopt the monetary policy rule used in Smets and Wouters (2003) since it is our goal to implement a policy that is also based on Taylor rule cross-checking.

3 Simulation

3.1 Simulation setup

As pointed out earlier, we assume that the monetary authority is faced with uncertainty on the side of the parameters of the data generating process. Consequently, the monetary authority is completely aware of the true structure of the economy but does not know all relevant parameters entirely.

At a first stage, we consider cases where only single elements of the parameter vector are estimated with error by the monetary authority whereas all remaining parameters are assumed to be known. We include those exercises to isolate the effects of misspecification in single parameters. In particular, we focus on the Phillips curve parameters which refer to Calvo price stickiness, ξ_p, and the degree of price indexation, γ_p. We do so because the Philips curve is of particular importance for the conduct of monetary policy. Note, however, that those illustrative cases shall not be regarded as adequate depictions of reality. We will return to this point later.

At a second stage, we think of the misspecification as being of a random nature.[6] In this case, parameter sets of the true model are randomly drawn. The parameters that we consider for misspecification are marked with "$*$" in tables 1 and 2. The reason for this choice is twofold. First, the standard deviations of the shocks that are incorporated in the reference model do not influence optimal monetary policy. This is the so-called certainty equivalence property (Svensson, 2010). Second, we exclude parameters that were calibrated in Smets and Wouters (2003) or are directly pinned down by those calibrations. Hence, we assume that those calibrated parameters are known. A monetary authority is naturally confronted with uncertainty about the economic environment that is not restricted to a subset of parameters only, let alone uncertainty about only a single parameter. Hence, it is not sufficient to consider uncertainty about single elements of the parameter

[6] We also considered the case of a systematic over- or underestimation of the model parameters. Even though it may or may not be realistic to assume that the monetary authority estimates all parameters of a DSGE model to be higher or lower than what they actually are, we analyzed those cases for completeness. Simulation results are not reported for brevity but are available from the authors upon request.

vector in order to assess the usefulness of Taylor rule cross-checking and to make normative statements for policy making institutions. In reality, a monetary authority will not be able to estimate the parameters of the true model without uncertainty. The parameter estimates will always be associated with corresponding standard errors. In order to incorporate this in our analysis, we assume that the parameters of the data generating process are the result of random draws and therefore in general differ from the reference model parameters. As such, we combine prior and posterior reasoning in order to fix a distribution for each parameter under consideration from which the corresponding parameter of the data generating process is drawn. This allows us to generate parameter draws that are in a reasonable range and ensures, for instance, that none of the autocorrelation coefficients of the shock processes are equal to or exceed unity. More precisely, we adopt the distributional assumption of the prior distribution for each parameter and subsequently fix the parameter pair (a, b) that uniquely identifies the distribution in a way such that the estimated posterior mode and standard deviation are perfectly reproduced.

Whether an estimation bias is small or large is naturally related to the standard deviation of the respective parameter estimate. Hence, we assume that the estimation bias is in fact related to the estimated standard deviation in Smets and Wouters (2003). Table 3 shows the parameters under consideration together with the distributional assumption, posterior estimation results, and the corresponding parameter pair (a, b) of the respective probability distribution.

Optimal monetary policy is obtained using the reference model of the monetary authority. The weighting parameter λ_y is initialliy fixed to 2/3. In reality, monetary authorities differ in the relative emphasis placed on their targets. While the ECB, for instance, is primarily concerned with price stability, the mandate of the Federal Reserve explicitly incorporates economic activity. Hence, we consider different values for the weighting parameter λ_y in order to investigate heterogeneity also in this respect. We are interested in the relative importance of the squared interest rate spread. Hence, we perform a series of simulations for different values of λ_Δ where the parameter is

Parameter	Distribution	Mode	S.D.	a	b
ρ_{ϵ_a}	Beta	0.823	0.065	29.094	7.042
ρ_{ϵ_b}	Beta	0.855	0.035	88.311	15.807
ρ_{ϵ_g}	Beta	0.949	0.029	65.572	4.470
ρ_{ϵ_l}	Beta	0.889	0.052	35.529	5.311
$\rho_{\epsilon_{inv}}$	Beta	0.927	0.022	137.148	11.721
h	Beta	0.573	0.076	23.603	17.844
ξ_w	Beta	0.737	0.049	59.129	21.743
ξ_p	Beta	0.908	0.011	632.285	64.963
γ_w	Beta	0.763	0.188	3.527	1.785
γ_p	Beta	0.469	0.103	10.610	11.880
$1/\varphi$	Normal	6.771	1.026	6.771	1.026
σ_c	Normal	1.353	0.282	1.353	0.282
σ_l	Normal	2.400	0.589	2.400	0.589
ϕ	Normal	1.408	0.166	1.408	0.166
$1/\psi$	Normal	0.169	0.075	0.169	0.075
σ_{ϵ_l}	Inv. Gamma	3.520	1.027	16.891	62.975
σ_{ϵ_a}	Inv. Gamma	0.598	0.113	33.553	20.663
σ_{ϵ_b}	Inv. Gamma	0.336	0.096	17.417	6.188
σ_g	Inv. Gamma	0.325	0.026	162.151	53.024
σ_π	Inv. Gamma	0.017	0.008	9.0412	0.1707
$\sigma_{\epsilon_{inv}}$	Inv. Gamma	0.085	0.030	12.942	1.185
σ_{λ_p}	Inv. Gamma	0.160	0.016	105.846	17.095
σ_{λ_w}	Inv. Gamma	0.289	0.027	120.438	35.096
σ_{ϵ_q}	Inv. Gamma	0.604	0.063	97.756	59.648

Table 3: a and b refer to mean and standard deviation for the normal distribution, to the shape parameters for the Beta distribution, and to shape and scale parameters for the Inverse Gamma distribution. Given the distributional assumptions, a and b are chosen in order to perfectly reproduce the respective posterior mode and standard deviation. Properties for the Inverse Gamma distribution are displayed for completeness and are used in a robustness exercise.

chosen to be in the range $[0; 0.25]$. The reason for this choice is twofold. First, Ilbas et al. (2012) find that already small weights attached to the squared interest rate spread are able to insure against bad outcomes. Second, we would naturally expect λ_Δ to be substantially smaller than the weights attached to stabilizing inflation or output, respectively. For the model simulations, the true model is used which is closed using the policy obtained from the optimization problem of the monetary authority using the reference model. Since squared deviations of the interest rate from the Taylor rule-implied interest rate are irrelevant from a welfare-theoretical perspective, there is no reason why one should evaluate the monetary authority's loss using the per period loss function given by equation (4) with $\lambda_\Delta \neq 0$. A reasonable alternative is to compute the loss with respect to the traditional per period loss function (1) even though the optimal policy is determined using (4). Therefore, it is important to note that for model evaluation and loss determination λ_Δ is set equal to zero in all cases. This is in line with Ilbas et al. (2012) and ensures comparability of the simulation results.

For each value of λ_Δ, we perform a set of $N = 250$ simulations[7], each using different realizations of the shock processes and containing $T = 5,000$ simulated quarters. By doing so, we ensure that for each set of simulated time series, simulated quarters that are more than T periods ahead are negligible for loss evaluation.

3.2 Simulation results - commitment

Figures 2 to 6 show the simulation results where figures 2 and 3 refer to the case where single model parameters are either over- or underestimated compared to the reference model that is used to determine monetary policy. Furthermore, we consider the case where the parameters of the true model are randomly drawn in figures 4 to 6. Except for figures 5 and 6, we plot in the upper panel the average relative loss between using the traditional loss function (1) for the determination of monetary policy and using loss function

[7]Results remain robust if the number of simulations N is increased. We therefore fixed it for computational convenience as stated in the main text.

(4) that is adjusted for a Taylor rule cross-checking term. When the respective values falls below 100%, adding the cross-checking term is on average not beneficial in terms of the monetary authority's objective. Since we simulate the true model for each value of λ_Δ $N = 250$ times, we end up with a whole distribution of relative losses such that we are able to compute the standard deviations of the relative losses. The respective plot can be found in the lower left panel. Furthermore, conditional on assuming Gaussian relative losses, we plot the probability that Taylor rule cross-checking is on average not beneficial for the monetary authority, in other words the probability that the relative loss will be smaller than 100%.

The case where ξ_p is lower compared to the reference model by one parameter standard deviation is depicted in figure 2. Putting even a very small weight on the Taylor rule cross-checking term worsens the situation of the monetary authority in terms of the relative loss. The average relative loss immediately falls below 100%, reflecting that the loss is smaller when sticking to the non-adjusted policy. A weight of $\lambda_\Delta = 0.1$, for instance, results in a loss which is on average about 6% larger compared to the loss incurred in the baseline case. The standard deviation increases and approaches a value of about 1.8% at $\lambda_\Delta = 0.25$. The lower right panel emphasizes that putting a positive weight on λ_Δ will almost always increase the loss. Hence, for this parameter specification, the monetary authority should not use the Taylor rule when deciding about its monetary policy as this has on average adverse effects on the associated losses.

Next, we analyze the case where ξ_p is higher compared to the reference model by one parameter standard deviation. The results in figure 3 are qualitatively similar compared to the previous case, in other words adjusting monetary policy for Taylor rule cross-checking deteriorates the monetary authority's loss. However, the effect is stronger. The standard deviation approaches a value slightly below 3%. The probability of ending up worse compared to the baseline case is around 100% and can hardly be distinguished from the certainty case.

It turns out that the results for Calvo wage stickiness, ξ_w, and the degrees of price and wage indexation, γ_p and γ_w, are qualitatively similar and are

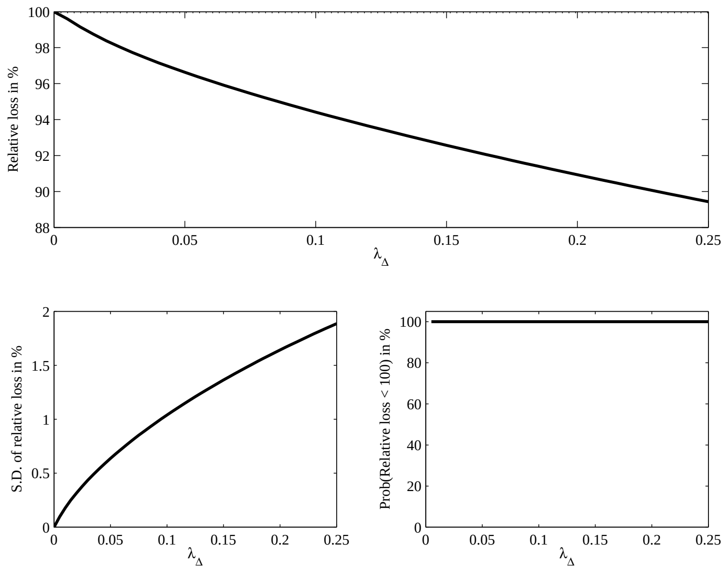

Figure 2: ξ_p is lower compared to the reference model by one parameter standard deviation (commitment case).

therefore skipped for brevity but available upon request. Also note that results are qualitatively similar for different values of λ_y. We return to the importance of λ_y for the efficiency of Taylor rule cross-checking in detail later. At this point, it is useful to emphasize that the above results are intuitive. Cross-checking necessarily increases the loss for the monetary authority if its reference model is almost identical to the true underlying economy as is the case in those exercises. In what follows, we will show that once we allow for a more realistic degree of uncertainty and different degrees of monetary policy commitment, results change such that cross-checking can be beneficial even though the reference model and the data generating process differ in parameter values only.

We now assume that misspecification is of random nature. In this case, nonlinear effects may be important such that the overall effect of Taylor rule cross-checking on the relative losses cannot be deduced from cases where only single elements of the parameter vector are misspecified. Whether or not Taylor rule cross-checking is beneficial for the monetary authority assuming this kind of realistic misspecification must therefore not only be based on

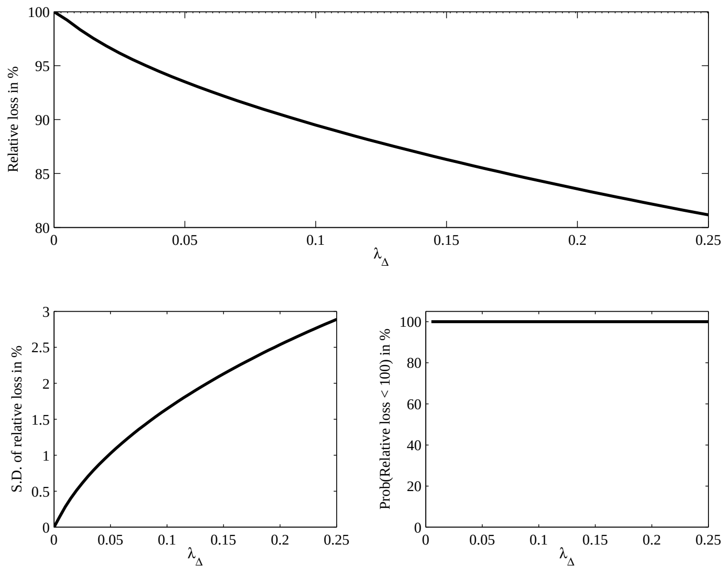

Figure 3: ξ_p is higher compared to the reference model by one parameter standard deviation (commitment case).

one single random parameter set. In order to make a normative statement one has to take into account that there is in principle an infinite number of different possible parameter combinations. Hence, we examine how Taylor rule cross-checking influences the relative losses when considering a variety of different parameter draws reflecting potential data generating processes. This will shed light on the average impact of Taylor rule cross-checking given that the true model is in the neighborhood of the monetary authority's reference model. We consider $N = 250$ different random parameter sets and simulate for each of those sets $T = 5,000$ quarters. Recall that for each of the $N = 250$ simulated series different realizations of the shock processes are used. Since we do not a priori know whether a certain combination of parameters leads to a determinate solution of the model, the parameter combinations have to be checked for determinacy first.[8] We end up with a

[8]Reconsidering the statements about the usefulness of the Taylor rule quoted in the introduction, it is likely that central banks indeed let the information resulting from simple instrument rules influence their policy decisions. Hence, we conclude that determinacy of the model even when including a Taylor rule cross-checking term in the monetary authority's loss function must be guaranteed. This justifies only considering determinate

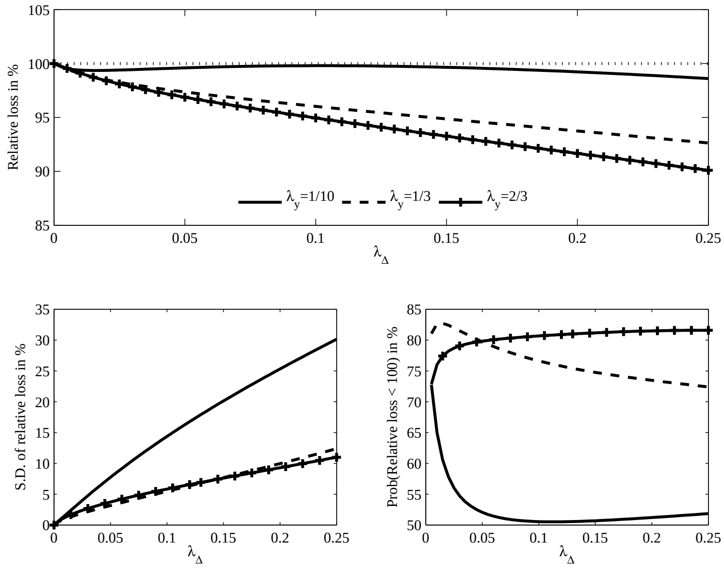

Figure 4: True parameters are drawn from the respective distribution given in table 3. For each of the $N = 250$ simulations, each containing $T = 5,000$ simulated quarters, a different random parameter set is used (commitment case).

total of 250 different parameter sets reflecting potential data generating processes at our disposal. The subsequent analysis is the same as before such that the corresponding results can be found in figure 4. The effectiveness of Taylor rule cross-checking crucially depends on the weight λ_y as a monetary authority on average benefits more from cross-checking the less it is concerned about economic activity. Comparing the three cases reveals that ceteris paribus losses are lower the lower λ_y.[9] However, it does not seem to be advisable to perform the type of cross-checking presented in this paper in the full commitment case. As we will show later, the degree of monetary policy commitment will also be of importance.

By construction, welfare effects shown before necessarily originate from

draws.

[9]The results remain qualitatively similar assuming a discount factor β of 0.995. Furthermore, results remain robust if the standard deviations of the shock processes are also considered for misspecification even though they do not influence optimal monetary policy (Svensson, 2010).

Taylor rule cross-checking as only the uncertainty case is considered. This raises the question how uncertainty affects the efficiency of Taylor rule cross-checking. In order to provide some intuition about the behavior of relative losses in the certainty case relative to the uncertainty case, we present related results in figure 5. In the certainty case, the monetary authority knows the model parameters. Hence, the reference model that is used in order to determine monetary policy coincides with the model reflecting the data generating process. The relative losses of the certainty case are depicted by dashed lines in the upper panels. By construction, $\lambda_\Delta > 0$ deteriorates the monetary authority's objective since a loss-minimizing policy requires setting $\lambda_\Delta = 0$. Put differently, the monetary authority cannot do better than following its optimal commitment policy when it has complete knowledge about the economy. The solid lines refer to the relative losses in the uncertainty case. The results on the left-hand side ($\lambda_y = 1/10$) and the right-hand side ($\lambda_y = 2/3$) are identical to those depicted in figure 4. We consider those two cases just for expositional purposes. In either of the cases, the relevant measure is the vertical difference between the two lines which is depicted in the respective lower panel. It is only of minor relevance in this context whether or not the threshold of 100% is exceeded. The difference can in fact be interpreted as the impact of uncertainty on the efficiency of Taylor rule cross-checking. In other words, a positive value as obtained in the simulations indicates that cross-checking becomes useful when moving from the certainty to the uncertainty case. As a monetary authority always faces uncertainty, however, only the uncertainty case remains relevant from a policy maker's perspective. Complete information about the data generating process necessarily renders Taylor rule cross-checking obsolete.

As stated before, the results in figure 4 suggest that the monetary authority's type influences the effectiveness of Taylor rule cross-checking significantly. In order to provide a more detailed picture of the impact of λ_y, we perform the exercise above for a grid of different values of λ_y reflecting different central bank types. Results are depicted in figure 6. We find that for a substantial number of parameter pairs $(\lambda_y, \lambda_\Delta)$ relative losses behave qualitatively similar compared to the case before where λ_y has been fixed

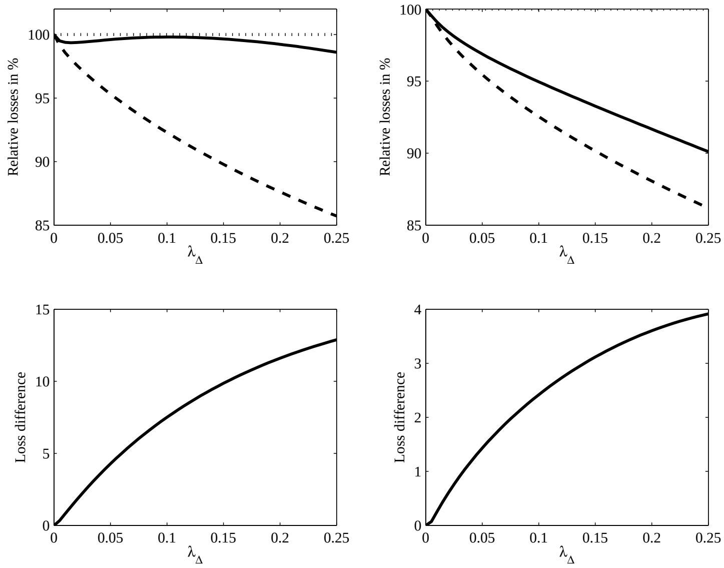

Figure 5: Comparison of cross-checking under uncertainty (solid line) and certainty (dashed line). The upper panels show the relative losses whereas the vertical difference in percentage points is depicted in the corresponding lower panel. The results on the left-hand side ($\lambda_y = 1/10$) and the right-hand side ($\lambda_y = 2/3$) refer to the simulation exercises depicted in figure 4 (commitment case).

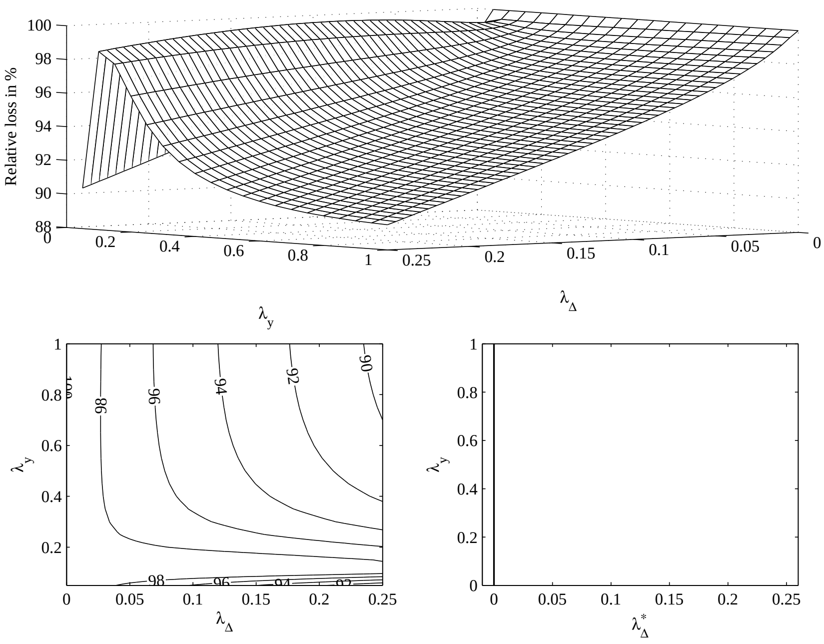

Figure 6: Relative losses and contour plot for different combinations of the relative weights λ_y and λ_Δ. The lower right panel plots the choice of λ_Δ as a function of λ_y. True parameters are drawn from the respective distribution given in table 3. For each of the $N = 250$ simulations, each containing $T = 5,000$ simulated quarters, a different random parameter set is used (commitment case).

to 2/3. Relative losses start at 100% by construction when $\lambda_\Delta = 0$ and decrease steadily with λ_Δ in most of the cases. Even though Taylor rule cross-checking turns out to be not beneficial in the full commitment case it is again worthwhile to emphasize that the monetary authority's type seems to influence its effectiveness significantly.

In general, different parameter sets will impact differently on the monetary authority's objective. Losses may be lower for some parameter combinations while they may be substantially higher for others. In particular the latter case is of importance if the monetary authority wants to insure against worst-case scenarios, in other words parameter combinations that produce overproportionally adverse outcomes. Hence, we shed light on the relationship between the severity of parameter misspecification reflected by the monetary authority's absolute losses and the effectiveness of Taylor rule cross-checking represented by the relative losses. The setup is similar to before and we simulate N economies for a range of λ_Δ and λ_y. Note, however, that the same realizations of the random shock processes are now considered for each of the simulations in order to make welfare effects resulting from parameter misspecification comparable. The absolute loss that the monetary authority would incur in a hypothetical scenario without cross-checking, in other words when $\lambda_\Delta = 0$ in the augmented loss function, is used as a measure of the severity of parameter misspecification. Put differently, parameter combinations that produce higher losses without cross-checking are interpreted as worst-case scenarios. Given that it would be arbitrary to present simulation results of a scenario using only one particular parameter draw, our aim is to analyze the relationship between the effectiveness of Taylor rule cross-checking and such worst-case scenarios in general. We operationalize this by calculating the coefficients of correlation between the series of N absolute non-cross-checking losses ($\lambda_\Delta = 0$) and the corresponding relative losses for different values of λ_Δ and λ_y. The respective plot can be found in figure 7. The positive coefficients of correlation indicate the following: Scenarios/-parameter combinations that yield higher absolute losses for the monetary authority assuming $\lambda_\Delta = 0$ tend to be associated with more effective Taylor-rule cross-checking (when $\lambda_\Delta > 0$) and vice versa. That is the sense in which cross-checking indeed insures against worst-case scenarios. The ability to insure against those bad outcomes tends to be stronger, the less the monetary authority is concerned about stabilizing economic activity and the smaller λ_Δ. In particular the former insight is supportive of our previous findings.

3.3 Simulation results - discretion

We drop the assumption that the monetary authority can credibly commit to an announced policy and assume instead that no commitment technology is available. As such, the monetary authority will not be able to perfectly manage expectations. Whether or not commitment or discretion is a more adequate depiction of reality is not obvious. Schaumburg and Tambalotti

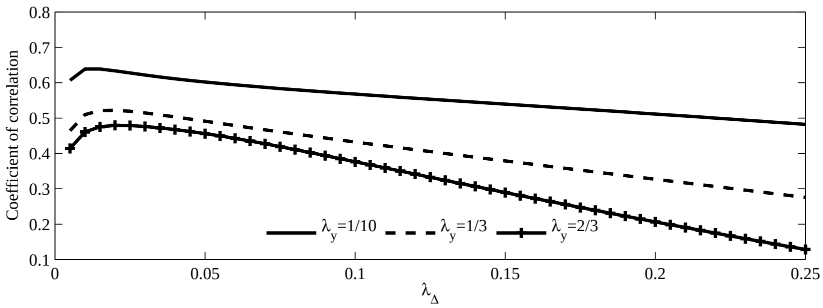

Figure 7: Coefficients of correlation between the monetary authority's absolute losses ($\lambda_\Delta = 0$) and the corresponding relative losses ($\lambda_\Delta > 0$). For each of the N simulations the same realizations of the random shock processes are used (commitment case).

(2007) and Debortoli and Nunes (2007), for instance, argue that an intermediate case may perhaps be more realistic.

The solution algorithms for the commitment and the discretion case differ significantly. In contrast to the commitment case finding optimal discretionary monetary policy is an iterative process and convergence properties are highly sensitive to parametrization as pointed out by Söderlind (1999). The simulation setup is identical to the one of the commitment case. Recall that figures 2 and 3 depicted cases where single elements of the parameter vectors were misspecified. Results do not change significantly for the discretionary policy maker and thus, we do not report comparable figures. The results where the misspecification is of a random nature can be found in figures 8 and 9.

Again, in order to make a normative statement, a variety of different parameter draws for different weights λ_y is considered in figure 8. Similar to the commitment case, reducing λ_y improves the efficiency of Taylor rule cross-checking. In contrast to before, however, for $\lambda_y = 1/10$ and over the whole range of λ_Δ, cross-checking on average improves the relative losses. A value of $\lambda_\Delta = 0.25$, for instance, produces a relative loss of about 112%.

In what follows, we again fully analyze the impact of λ_y on the monetary authority's objective. Results are depicted in figure 9. Again, we find that

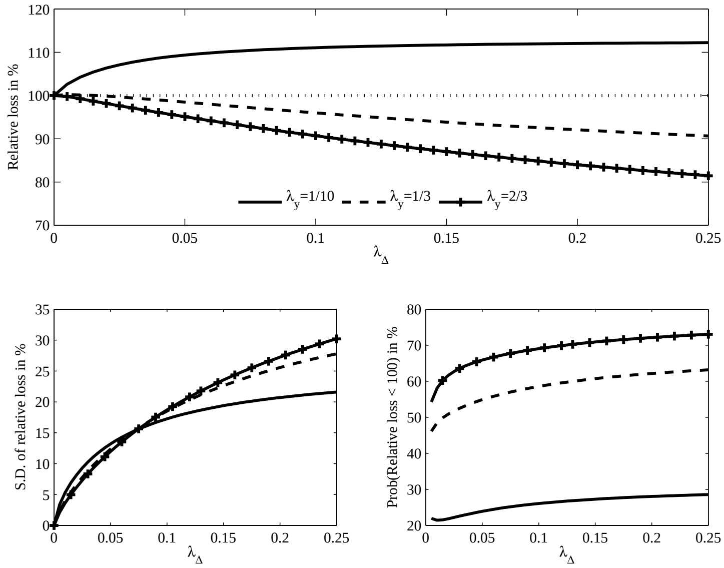

Figure 8: True parameters are drawn from the respective distribution given in table 3. For each of the $N = 250$ simulations, each containing $T = 5,000$ simulated quarters, a different random parameter set is used (discretionary case).

results are qualitatively similar to the ones obtained in the commitment case in the sense that low values of λ_y tend to increase the efficiency of Taylor rule cross-checking ex ante. Most importantly, we find that adjusting the policy instrument in the direction of the Taylor rule has a stronger impact in the discretionary case. When the monetary authority only moderately cares about output relative to inflation stabilization, Taylor rule cross-checking turns out to be on average beneficial. This case is potentially relevant for the Eurosystem as the mandate of the ECB emphasizes the inflation objective as the primary target of its monetary policy strategy. If the weight on output stabilization is less than or equal to 20% of the weight on inflation stabilization, the monetary authority is on average able to improve its loss independent of the chosen value of λ_Δ. Summing up, our results suggest that Taylor rule cross-checking can be beneficial even in a setup where the monetary authority is sufficiently confident about its reference model at hand and that the central bank type influences the effectiveness of cross-checking significantly. We conclude that cross-checking is more effective the less the monetary authority cares about output stabilization and the lower the degree of monetary policy commitment.

4 Conclusion

This paper builds upon Ilbas et al. (2012) and sheds light on the question whether the robustifying nature of Taylor rule cross-checking in their spirit carries over to the case of parameter uncertainty. We consider certainty with respect to the structure of the economy but uncertainty of the monetary authority about model parameters. In particular, we examine how much attention the monetary authority should pay to choosing the relative weight λ_Δ for the conduct of its monetary policy and how results are sensitive to changes in the monetary authority's type and its degree of commitment.

Our results suggest that even though the monetary authority is faced with uncertainty, it should be prudent in letting information resulting from Taylor rule cross-checking of the kind presented in this paper influence the conduct of its monetary policy. Put differently, while Taylor-rule cross-checking has

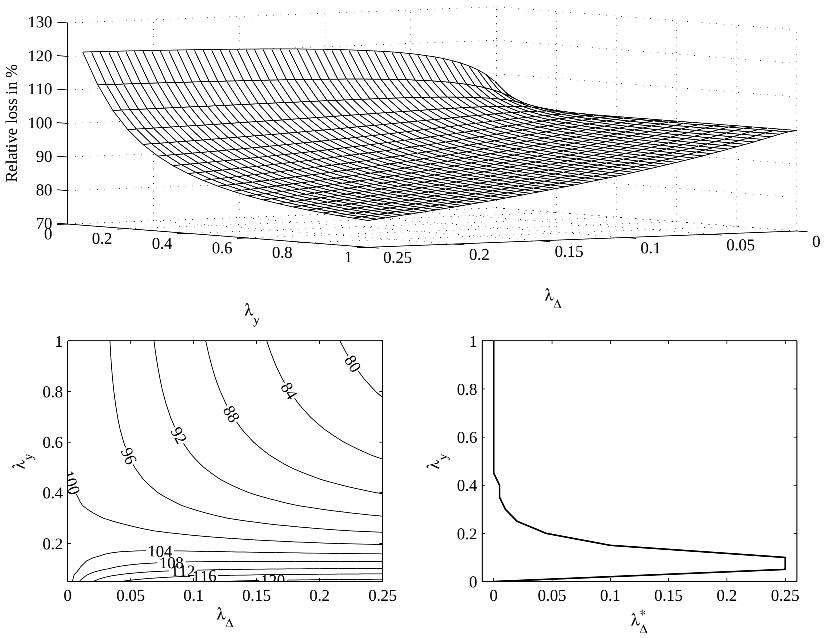

Figure 9: Relative losses and contour plot for different combinations of the relative weights λ_y and λ_Δ. The lower right panel plots the choice of λ_Δ as a function of λ_y. True parameters are drawn from the respective distribution given in table 3. For each of the $N = 250$ simulations, each containing $T = 5,000$ simulated quarters, a different random parameter set is used (discretionary case).

shown to be beneficial in cases where the monetary authority is faced with different potentially non-nested models reflecting diverse representations of the true economy, this result does not necessarily carry over to other forms of uncertainty where the true model of the economy lies in the neighborhood of the monetary authority's reference model.

Whether or not cross-checking is on average able to reduce the monetary authority's loss incurred from inflation and output deviating from the respective steady-state values crucially hinges on its type reflected by the relative importance it attaches to output stabilization and also the degree of monetary policy commitment. Much attention should be paid to choosing the appropriate relative weight λ_Δ. This point is pivotal as we find that for high values of λ_y, for instance, putting already small weights on the Taylor rule cross-checking term in an uncertain environment may have severe effects on the monetary policy objective.

As the monetary authority knows its own type and its degree of commitment, it can choose λ_Δ optimally. We find that when the monetary authority sets its policy in a discretionary way and at the same time only moderately cares about output stabilization, Taylor rule cross-checking is on average able to improve the associated losses. This insight deserves more attention in future research and may potentially justify Taylor rule cross-checking for the Eurosystem where output stabilization is generally considered a second order objective.

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