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A New Comparative Approach to Macroeconomic Modeling and Policy Analysis

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Abstract

In the aftermath of the global financial crisis, the state of macroeconomic modeling and the use of macroeconomic models in policy analysis has come under heavy criticism. Macroeconomists in academia and policy institutions are blamed for relying too much on a particular class of macroeconomic models that did not sufficiently. This paper proposes a comparative approach to macroeconomic policy analysis that is open to competing modeling paradigms. Macroeconomic model comparison projects have helped produce some very influential insights such as the Taylor rule. However, they have been infrequent and costly, because they require the input of many teams of researchers and multiple meetings to obtain a limited set of comparative findings. This paper provides a new comparative approach to model-based research and policy analysis that enables individual researchers to conduct model comparisons easily, frequently, at low cost and on a large scale. Using this approach a model archive is built that includes many well-known empirically estimated models that may be used for quantitative analysis of monetary and fiscal stabilization policies. A computational platform is created that allows straightforward comparisons of models' implications. Its application is illustrated by comparing different monetary and fiscal policies across selected models. Researchers can easily include new models in the data base and compare the effects of novel extensions to established benchmarks thereby fostering a comparative instead of insular approach to model development.

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1 Introduction

The global financial crisis surprised many policy makers, their advisers as well as many professionals including business forecasters, finance experts and economists with expertise in finance or macroeconomics. Media and other commentators have criticized macroeconomists, in particular, for failing to predict the great recession of 2008-09 or at least failing to provide adequate warning of the risk of such a recession ahead of time. Practitioners have attributed this failure to academic and central bank researchers' use of a particular modeling paradigm. They blame so-called dynamic stochastic general equilibrium (DSGE) models for misdirecting their attention. Indeed, even some well-known academics-cum-bloggers have published scathing commentaries on the current state of macroeconomic modeling. In March 2009, Willem Buiter wrote " ... *the typical graduate macroeconomics and monetary economics training received at Anglo-American universities during the past 30 years or so, may have set back by decades serious investigations of aggregate economic behavior and economic policy-relevant understanding.*"ï£¡ He was echoed by Nobel Prize Winner Paul Krugman in the Economist, June 2010, " *Most work in macro-economics in the past 30 years has been useless at best and harmful at worst.*"

Against this background, the present paper aims to develop a more constructive proposal for how to use macroeconomic modeling - whether state-of-the-art or 1970s-vintage - in practical policy design. In the spirit of the 1992 call by leading economists – among them Nobel prize winners Paul Samuelson and Franco Modigliani – for a pluralistic and rigorous economics, we propose a systematic comparative approach to macroeconomic modeling with the objective of identifying policy recommendations that are robust to model uncertainty.[1] This approach is open to a wide variety of modeling paradigms. Scientific rigor demands a level-playing field on which models can compete. Instead of using rhetoric to dismiss competing approaches, models should be required to satisfy empirical benchmarks. For example, models used for monetary policy analysis should be estimated to fit key time series such as output, inflation and nominal interest rates. Models should be able to provide answers to typical policymakers' questions.

Macroeconomic data, however, are unlikely to provide sufficient testing grounds for selecting a single, preferred model for policy purposes. if many of the competing models describe historical data of key aggregates reasonably well, one could use these models to establish "robustness" of policy recommendations. Such an approach is recommended by McCallum (1988, 1989), Blanchard and Fischer (1989), Taylor (1999) and many others. McCallum (1999), for example, proposes *" to search for a policy rule that possesses robustness in the sense of yielding reasonably desirable outcomes in*

[1]The undersigned were concerned with "*the threat to economic science posed by intellectual monopoly*" and pleaded for "*a new spirit of pluralism in economics, involving critical conversation and tolerant communication between different approaches*". See the advertisement section of the American Economic Review - AEA Papers and Proceedings issue of May 1992.

policy simulation experiments in a wide variety of models." [2] Recently, ECB President Jean-Claude Trichet expressed the need for robustness as follows:

> "*We need macroeconomic and financial models to discipline and structure our judgemental analysis. How should such models evolve? The key lesson I would draw from our experience is the danger of relying on a single tool, methodology or paradigm. Policy-makers need to have input from various theoretical perspectives and from a range of empirical approaches. Open debate and a diversity of views must be cultivated - admittedly not always an easy task in an institution such as a central bank. We do not need to throw out our DSGE and asset-pricing models: rather we need to develop complementary tools to improve the robustness of our overall framework".*[3]

Yet, systematic comparisons of the empirical implications of a large variety of available models are rare. Evaluating the performance of different policies across many models typically is work intensive and costly. The seven comparison projects reported in Bryant, Henderson, Holtham, Hooper, and Symansky (1988), Bryant, Currie, Frenkel, Masson, and Portes (1989), Klein (1991), Bryant, Hooper, and Mann (1993), Taylor (1999), Hughes-Hallett and Wallis (2004) and Coenen, Erceg, Freedman, Furceri, Kumhof, Lalonde, Laxton, Lindï£¡, Mourougane, Muir, Mursula, de Resende, Roberts, Roeger, Snudden, Trabandt, and in't Veld (2010) have involved multiple teams of researchers, each team working only with one or a small subset of available models. While these initiatives have helped produce some very influential insights such as the Taylor rule,[4] the range of systematic, comparative findings has remained limited.

This paper provides a new comparative approach to model-based research and policy analysis that enables individual researchers to conduct systematic model comparisons and policy evaluations easily and at low cost. Following this approach it is straightforward to include new models and compare their empirical and policy implications to a large number of established benchmarks.

We start by presenting a formal exposition of our approach to model comparison. A general class of nonlinear dynamic stochastic macroeconomic models is augmented with a space of common comparable variables, parameters and shocks. Augmenting models in this manner is a necessary pre-condition for a systematic comparison of particular model characteristics. On this basis, common policy rules can be defined as model input. Then we derive comparable objects that may be produced as model output. These objects are also defined in terms of common variables, parame-

[2] Taylor and Wieland (2011) follow this recommendation and investigate the policy implications of three well-known models of the U.S. economy available in this data base.

[3] This quote is taken from a speech by Jean-Claude Trichet, President of the ECB, titled "Reflections on the nature of monetary policy non-standard measures and finance theory" on the occasion of the ECB Central Banking Conference Frankfurt, 18 November 2010.

[4] Taylor (1993b) credits the comparison project summarized in Bryant et al. (1993) as the crucial testing ground for what later became known as the Taylor rule.

ters and shocks. Examples for such objects are impulse response functions, autocorrelation functions and unconditional distributions of key macroeconomic aggregates. An illustrative example with two well-known small New Keynesian models is provided.

Next, we give a brief overview of the model archive that we have built. This data base includes many well-known empirically-estimated macroeconomic models that may be used for quantitative analysis of monetary and fiscal stabilization policies. These are models of the U.S. and euro area economies and several multi-country models. Some of the models are fairly small and focus on explaining output, inflation and interest rate dynamics (cf. Clarida et al (1999), Rotemberg and Woodford (1997), Fuhrer and Moore (1995), McCallum and Nelson (1999), Coenen and Wieland (2003), etc.). Others are of medium scale and cover many key macroeconomic aggregates (cf. Christiano, Eichenbaum and Evans (2005), Coenen, Orphanides, and Wieland (2004), Smets and Wouters (2003, 2007)). Some models in the data base are fairly large in scale such as the Federal Reserve's FRB-US model of Reifschneider, Tetlow, and Williams (1999), the model of the G7 economies of Taylor (1993a) or the ECB's Area-wide model of Dieppe, Kuester, and McAdam (2005). Most of the models can be classified as New Keynesian models because they incorporate rational expectations, imperfect competition and wage or price rigidities. Many of these New-Keynesian models fully incorporate recent advances in terms of microeconomic foundations. Well-known examples of this class are models by Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003, 2007), Laxton and Pesenti (2003) and Adolfson, Laseen, Linde, and Villani (2007). In addition, we have included models that assign little role to forward-looking behavior by economic agents (cf. the ECB's area-wide model) or none at all (cf. Rudebusch and Svensson (1999) and Orphanides (2003)).

We have created a computational platform that implements our approach to model comparison. It allows users to solve structural models and conduct comparative analysis. Comparisons of impulse response functions of common variables in response to common shocks, or of autocorrelation functions of common variables in response to model-specific shocks, or of unconditional distributions of common variables are generated. It can also be used to conduct a systematic investigation of policy rules across models. The platform admits nonlinear as well as linear models and allows for perturbation-based approximation of nonlinear models with forward-looking variables as well as two-point boundary value-based approximation. [5] New models may easily be introduced and compared to established benchmarks thereby fostering a comparative rather than insular approach to model building. New modeling approaches may offer more sophisticated explanations of the sources of the great recession of 2008-09 and carry the promise of improved forecasting performance. This promise can be put to a test as in Wieland and Wolters (2011).

Finally, the comparative approach to modeling and policy analysis is illustrated with several ex-

[5] This software is written for MATLAB and utilizes DYNARE software for model solution. For further information on DYNARE see Juillard (2001) and Juillard (1996).

amples. We compare monetary and fiscal policy shocks under alternative monetary policy rules, and investigate the predictions of different models and different policies for inflation and output persistence. A detailed description of the model comparison software and of the models included in the data base is provided in the appendices A and B, respectively.

2 A general approach to model comparison

Macroeconomic models differ in terms of modeling assumptions. They may include different economic concepts and therefore different variables and parameters; they may use different policy rules; and invariably they tend to use different notation and definitions of the same key macroeconomic aggregates. As a consequence, model output is not directly comparable. In the following, we describe formally how to augment any model in a way that renders comparison of policy implications across models straightforward, while keeping the number of necessary modifications of the original models at a minimum.

2.1 Augmenting models for the purpose of comparison

We start by introducing the notation for a general nonlinear macroeconomic model of the economy. The letter m is used to refer to a specific model considered in the comparison. Thus, $m = (1, 2, 3, ..., M)$ will appear as a superscript on any variables or parameters that are part of this model.[6] These variables or parameters need not be comparable across models nor follow particular naming conventions across models. Our notation regarding the vectors model-specific variables, parameters, and shocks is summarized in **Table 1**.

Table 1: Model-Specific Variables, Parameters, Shocks and Equations

Notation	Description
x_t^m	endogenous variables in model *m*
$x_t^{m,g}$	policy variables in model *m* (also included in x_t^m)
η_t^m	policy shocks in model *m*
ϵ_t^m	other economic shocks in model *m*
$g_m(.)$	policy rules in model *m*
$f_m(.)$	other model equations in model *m*
γ^m	policy rule parameters in model *m*
β^m	other economic parameters in model *m*
Σ^m	covariance matrix of shocks in model *m*

We distinguish two types of model equations, policy rules, which we denote by $g_m(.)$, and the

[6] In the computational implementation m may be associated with a particular list of model names rather than a list of numbers.

other equations and identities that make up the rest of the model, that we denote by $f_m(.)$. The two types of equations together determine the endogenous model variables, which are denoted by the vector x_t^m. The model variables are functions of each other, of model-specific shocks, $(\epsilon_t^m \eta_t^m)$, and of model parameters $(\beta^m \gamma^m)$. A particular model m may then be defined as follows:

$$E_t[g_m(x_t^m, x_{t+1}^m, x_{t-1}^m, \eta_t^m, \gamma^m)] = 0 \quad (1)$$

$$E_t[f_m(x_t^m, x_{t+1}^m, x_{t-1}^m, \epsilon_t^m, \beta^m)] = 0 \quad (2)$$

The superscript m refers to the original version of the respective model as supplied by the developers. The model may include current values, lags and the expectation of leads of endogenous variables. In equations (1) and (2) the lead- and lag-lengths are set to unity. This assumption is for notational convenience only and should not be understood as a restriction on the type of model that is admitted.[7]

The model may also include innovations that are random variables with zero mean and covariance matrix, Σ^m:

$$E([\eta_t^m \epsilon_t^m]') = 0 \quad (3)$$

$$E([\eta_t^{m\prime} \epsilon_t^{m\prime}]'[\eta_t^{m\prime} \epsilon_t^{m\prime}]) = \Sigma^m = \begin{pmatrix} \Sigma_\eta^m & \Sigma_{\eta\epsilon}^m \\ \Sigma_{\eta\epsilon}^m & \Sigma_\epsilon^m \end{pmatrix} \quad (4)$$

In the following we refer to innovations interchangeably as shocks. Some model authors instead differentiate between serially correlated economic shocks that are themselves functions of random innovations. This practice does not prevent us from including such models in a comparison. The serially correlated economic shocks of these authors would appear as elements of the vector of endogenous variables x_t^m and only their innovations would appear as shocks in our notation. Equation (4) distinguishes the covariance matrices of policy shocks and other economic shocks as Σ_η^m and Σ_ϵ^m. The correlation of policy shocks and other shocks is typically assumed to be zero, $\Sigma_{\eta\epsilon}^m = 0$.

If one wants to compare the implications of different models, it is necessary to define a limited set of comparable variables, shocks and parameters that will be in common to all models considered in the comparison exercise. It is then possible to express policies in terms of particular parameters, variables and policy shocks that are identical across models, and study the consequences of these policies for a set of endogenous variables that are defined in a comparable manner across models. Our notation for common endogenous variables, policy instruments, policy shocks, policy rules and parameters is introduced in **Table 2**.

Any model that is meant to be included in a comparison first has to be augmented with common variables, parameters and shocks. Augmenting the model implies adding equations. These additional equations serve to define the common variables in terms of model specific variables. We denote these

[7] The software implementation does not restrict the lead- and lag-lengths of participating models.

Table 2: Comparable Common Variables, Parameters, Shocks and Equations

Notation	Description
z_t	common variables in all models
z_t^g	common policy variables in all models (also included in z_t)
η_t	common policy shocks in all models
$g(.)$	common policy rules
γ	common policy rule parameters

definitional equations or identities by $h_m(.)$. By their nature they are model-specific. A further step is to replace the original model-specific policy rules with the common policy rules. All the other equations, variables, parameters and shocks may be preserved in the original notation of the model developers. As a consequence, the augmented model consists of three components: (i) the common policy rules, $g(.)$, expressed in terms of common variables, z_t, policy shocks, η_t, and policy rule parameters, γ; (ii) the model-specific definitions of common variables in terms of original model-specific endogenous variables, $h_m(.)$, with parameters θ^m; (iii) the original set of model-specific equations $f_m(.)$ that determine the endogenous variables. Thus, the augmented model may be represented as follows:

$$E_t[g(z_t, z_{t+1}, z_{t-1}, \eta_t, \gamma)] = 0 \tag{5}$$

$$E_t[h_m(z_t, x_t^m, x_{t+1}^m, x_{t-1}^m, \theta^m)] = 0 \tag{6}$$

$$E_t[f_m(x_t^m, x_{t+1}^m, x_{t-1}^m, \epsilon_t^m, \beta^m)] = 0 \tag{7}$$

Models augmented in this manner can be used in comparison exercises. For example, it is possible to compare the implications of a particular policy rule for the dynamic properties of those endogenous variables that are defined in a comparable manner across models. An advantage of this approach is that it requires only a limited set of common elements. With regard to the remainder of the model the original notation used by model authors can be left unchanged, in particular the variable names and definitions of endogenous variables, x_t^m, the other economic shocks ϵ_t^m, the equations $f_m(.)$ with model parameters β^m and the covariance matrix of shocks Σ_ϵ^m. The covariance matrix of policy shocks Σ_η may be treated as an element of the vector of policy parameters or constrained to zero.

The essential step in introducing a new model in a comparison exercise is to define the common variables in terms of model-specific variables. It involves setting up the additional equations, $h_m(.)$, and determining the definitional parameters, θ^m. We illustrate this process with an example.

A simple example

The vector of common variables, z_t, is assumed to contain six variables that are meant to be comparable across models:

$$z_t = [\ i_t^z \quad g_t^z \quad \pi_t^z \quad p_t^z \quad y_t^z \quad q_t^z\ ]' \tag{8}$$

These variables are characterized in **Table 3**. They are expressed in percentage deviations from steady state values, because the example applies to linear models. The monetary policy instrument is

Table 3: Comparable Common Variables

Notation	Description
i_t^z	annualized quarterly money market rate
g_t^z	discretionary government spending (share in GDP)
π_t^z	year-on-year rate of inflation
p_t^z	annualized quarter-to-quarter rate of inflation
y_t^z	quarterly real GDP
q_t^z	quarterly output gap (dev. from flex-price level)

the annualized short-term money market rate in quarter t denoted by i_t^z. The fiscal policy instrument is discretionary government spending expressed in terms of its share in GDP and denoted by g_t^z. Economic outcomes are measured with regard to inflation, real output and the output gap. π_t^z denotes the year-on-year rate of inflation, while p_t^z refers to the annualized quarter-to-quarter rate of inflation. y_t^z is quarterly real GDP. q_t^z refers to the output gap defined as the difference between actual output and the level of output that would be realized if the price level were flexible.[8]

Next, we define common monetary and fiscal policy rules. The monetary rule serves to determine the nominal interest rate, i_t^z. It includes a systematic response to output and inflation, defined in comparable terms, as well as a monetary policy shock. The fiscal rule determines discretionary government spending, g_t^z. It is simply defined as the product of a random innovation and a policy parameter:

$$i_t^z = \gamma_i i_{t-1}^z + \gamma_p p_t^z + \gamma_q q_t^z + \eta_t^i \tag{9}$$

$$g_t^z = \gamma_g \eta_t^g \tag{10}$$

The common policy shocks and parameters are denoted by:

$$\eta_t = [\ \eta_t^i \quad \eta_t^g\ ] \tag{11}$$

$$\gamma = [\ \gamma_i \quad \gamma_p \quad \gamma_q \quad \gamma_g\ ] \tag{12}$$

[8]The latter concept of potential output is used in whichever way a particular model defines it. Another interesting exercise would be to compare different concepts of potential output and output gaps across models by introducing additional common variables.

Having defined common variables, shocks and policy parameter, we proceed to consider two simple New-Keynesian models for conducting a model comparison, $m = \{1, 2\}$. One model is taken from Clarida, Gali, and Gertler (1999), ($m = 1$ refers to the model name NK_CGG99), while the other one is from Woodford (2003) and based on Rotemberg and Woodford (1997), ($m = 2$ refers to NK_RW97). These are well-known benchmarks in the literature. We present the original model equations as published by the authors and then show how to augment them appropriately for a comparison exercise. This step may seem trivial in the case of such simple models, but it is nevertheless important in order to avoid a case of comparing apples and oranges.

Table 4: Model 1 - The hybrid model of Clarida et al. (1999) (NK_CGG99)

Description	Equations and Definitions
Original Model	
variables	$x_t^1 = [\ i_t \quad x_t \quad \pi_t\ ]', \quad x_t^{1,g} = [i_t]$
shocks	$\epsilon_t^1 = [\ g_t \quad u_t\ ]'$
parameters	$\beta_1 = [\ \varphi \quad \theta \quad \phi\ ]', \quad \gamma_1 \quad = [\ \alpha \quad \gamma_\pi \quad \gamma_x\ ]'$
model equations	
$g_1(.)$	$i_t = \alpha + \gamma_\pi(\pi_t - \bar{\pi}) + \gamma_x x_t$
$f_1(.)$	$x_t = -\varphi(i_t - E_t\pi_{t+1}) + \theta x_{t-1} + (1-\theta)E_t x_{t+1} + g_t$
...	$\pi_t = \lambda x_t + \phi\pi_{t-1} + (1-\phi)\beta E_t\pi_{t+1} + u_t$
Augmented Model	
$z_t, \eta_t, \gamma, g(.)$	as defined by equations (8-12).
$f_1(.)$	as defined above in original model.
$h_1(z_t, x_t^1, E_t x_{t+1}^1, x_{t-1}^1, \theta^1)$	$i_t^z = 4i_t$
...	$\pi_t^z = \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}$
...	$p_t^z = 4\pi_t$
...	$q_t^z = x_t$

The Clarida et al. (1999) model is presented in **Table 4**. The model in the authors' notation consists of three equations: (i) a Phillips curve relating quarterly inflation, π_t, to inflation expectations, past inflation, the output gap, x_t, and a cost-push shock, u_t; (ii) an IS equation relating the current output gap to past and expected future gaps, the expected real interest rate, $i_t - E_t\pi_{t+1}$, and a demand shock, g_t; (iii) and a policy rule relating the quarterly interest rate to inflation and the output gap.[9] Clarida et al. (1999) call it the hybrid model because it involves forward- and backward-looking elements in the Phillips and IS curves.

In the augmented version of the model the original policy rule is replaced with the common

[9]These are equations 6.1, 6.2 and 7.1 in Clarida et al. (1999) respectively.

rule, equation (7). The other equations from the original model, $f_m(.) = f_1(.)$, remain unchanged. The additional equations in the augmented model, $h_m(., \theta^m) = h_1(., \theta^1)$, provide the appropriate definitions of common comparable variables in terms of model-specific variables.[10]

Table 5: Model 2 - The New-Keynesian model of Woodford (2003) (NK_RW97)

Description	Equations and Definitions
Original Model	
variables	$x_t^2 = [\ \hat{i}_t \quad \pi_t \quad x_t \quad \hat{r}_t^n \quad g_t \quad u_t \quad y_t \quad y_t^n\ ]', \quad x_t^{2,g} = [\hat{i}_t]$
shocks	$\epsilon_t^2 = [\ \epsilon_{u,t}\ ] \quad \eta_t^{2,g} = [\epsilon_{g,t}]$
parameters	$\beta^2 = [\ \beta \quad \kappa \quad \sigma \quad \rho_g \quad \rho_u \quad \omega\ ]', \ \gamma_2 = [\ \phi_\pi \quad \phi_x \quad \bar{\pi} \quad \bar{x}\ ]'$
model equations	
$g_2(.)$	$\hat{i}_t = \bar{i}_t + \phi_\pi(\pi_t - \bar{\pi}) + \frac{\phi_x}{4}(x_t - \bar{x})$
$f_2(.)$	$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + u_t$
...	$x_t = E_t x_{t+1} - \sigma(\hat{i}_t - E_t \pi_{t+1} - \hat{r}_t^n)$
...	$\hat{r}_t^n = \sigma^{-1}[(g_t - y_t^n) - E_t(g_{t+1} - y_{t+1}^n)]$
...	$g_t = \rho_g g_{t-1} + \epsilon_{g,t}$
...	$u_t = \rho_u u_{t-1} + \epsilon_{u,t}$
...	$y_t = x_t + y_t^n$
...	$y_t^n = \frac{\sigma^{-1}}{\omega + \sigma^{-1}} g_t$
Augmented Model	
$z_t, \eta_t, \gamma, g(.)$	as defined by equations (8-12).
$f_2(.)$	as defined above in original model.
$h_2(z_t, x_t^2, , E_t x_{t+1}^2, x_{t-1}^2 \theta^2)$	$i_t^z = 4\hat{i}_t$
...	$g_t^z = \epsilon_{g,t}$
...	$\pi_t^z = \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}$
...	$p_t^z = 4\pi_t$
...	$y_t^z = y_t$
...	$q_t^z = x_t$

The Rotemberg and Woodford (1997) model is presented in **Table 5**. For simplicity, the linearized version is used. Of course, the nonlinear version could similarly be augmented for comparison purposes following the approach outlined in this paper. There are some interesting differences to the hybrid model of Clarida et al. (1999). The Rotemberg-Woodford model does not exhibit endogenous

[10]This model is defined in terms of the output gap relative to a variable called flexible price output without further information on the determination of said variable. Thus, a comparable definition of the level of output is not available in this model. Therefore, this model remains silent on the time series characteristics of the level of output, y_t^z, in the comparison exercise. It is important that a systematic approach to model comparison identifies such cases so as to avoid comparing apples and oranges. Furthermore, the model does not explicitly include government spending. Therefore, it also remains silent with regard to the common variable g_t^z.

persistence due to the inclusion of lagged inflation and output in the Phillips and IS curves. Instead, however, it allows for persistence in the exogenous shocks. Furthermore, it includes government spending, the natural real interest rate and the natural level of output explicitly. The model in the notation of Woodford (2003) consists of eight equations[11]: (i) a policy rule determining the nominal interest rate, $\hat{i}_t$; (ii) a purely forward-looking Phillips curve equation that determines quarterly inflation, π_t; (iii) a forward-looking IS equation determining the quarterly output gap x_t; (iv) a definition of the natural rate of interest, $\hat{r}_t^n$; (v,vi) definitions of serially correlated government spending dynamics, g_t, and cost-push shocks u_t with random innovations,[12] $\epsilon_{g,t}$ and $\epsilon_{u,t}$; (vii,viii) and definitions of output, y_t, and the natural level of output, y_t^n.

2.2 Conducting a comparison

Given models augmented with common policy rules and comparable variables it is possible to conduct a proper comparison. It requires solving the augmented models, constructing appropriate objects for comparison, and defining a metric that quantifies the differences of interest.

Model solution

A solution to the general nonlinear model is obtained by solving out the expectations of future variables conditional on the available information. This step requires an assumption of how expectations are formed. So far, we have used the statistical expectation that is appropriate for models with rational expectations. Solution methods for linear and nonlinear models with rational expectations are available and implemented in the computational platform provided with the paper. Most of the models in the data base assume rational expectations. However, other assumptions regarding expectations formation can also be admitted.[13] Existence and uniqueness of equilibrium also need to be checked in the solution step.[14] The solution of the structural nonlinear model may then be expressed in terms of the following nonlinear reduced-form equations:

$$z_t = k_z(z_{t-1}, x_{t-1}^m, \eta_t, \epsilon_t^m, \kappa_z) \tag{13}$$

$$x_t^m = k_x(z_{t-1}, x_{t-1}^m, \eta_t, \epsilon_t^m, \kappa_x) \tag{14}$$

(κ_z, κ_x) denote the reduced-form parameters, which are complex functions of the structural parameters, β^m, the policy parameters, γ, and the covariance matrix Σ^m.

[11] See Woodford (2003), page 246-247, equations 1.12-1.14, 2.2-2.4.

[12] In the quantitative analysis we rely on estimates of the autoregressive parameters in the shock processes provided by Adam and Billi (2006), while we obtained the structural parameters from Woodford (2003).

[13] Examples would be the introduction of adaptive learning in the Smets and Wouters (2007) model by Slobodyan and Wouters (2007), or a version of the FRB-US model with VAR-based expectations instead of rational expectations.

[14] In linear models the Blanchard-Kahn conditions provide the necessary information. In nonlinear models one may have to resort to search by means of numerical methods.

Solutions of the nonlinear model can be obtained using numerical methods, for example, perturbation-based, projection-based or two-point-boundary-value algorithms (see Judd (1998), Fair and Taylor (1983), Collard and Juillard (2001)) or by linearizing it around a deterministic steady state and using the methods of Uhlig (1995) (generalized eigenvalue-eigenvector problem), Klein (2000) (generalized Shur decomposition), Sims (2001) (QZ decomposition), Christiano (2002) (undetermined coefficients) and many others.

In the remainder of this section we consider the first-order approximation to the reduced form solution of the augmented nonlinear model and show how it may be used to obtain particular objects for comparison defined in terms of comparable variables. The first-order that is linear approximation to the nonlinear solution (or the linear solution to originally linear models as in the preceding example) is given by:

$$\begin{pmatrix} z_t \\ x_t^m \end{pmatrix} = K_m(\gamma) \begin{pmatrix} z_{t-1} \\ x_{t-1}^m \end{pmatrix} + D_m(\gamma) \begin{pmatrix} \eta_t \\ \epsilon_t^m \end{pmatrix} \tag{15}$$

where the reduced-form matrices $K_m(\gamma)$ and $D_m(\gamma)$ are complicated functions of the structural parameters including the policy parameters, γ. We denote the dependence on the other (model specific) parameters β^m with the subcript m.

With the linear reduced form in hand one can derive particular objects for comparison, for example, the dynamic response of a particular common variable (an element of z) to a policy shock conditional on a certain policy rule. Impulse response functions describe the isolated effect of a single shock on the dynamic system holding everything else constant. Formally the impulse response functions in period $t+j$ to the common monetary policy shock η_t^i are defined as:

$$IR_{t+j}^m(\gamma;\eta^i) = \begin{pmatrix} E[z_{t+j}|z_{t-1}, x_{t-1}^m, I_t] - E[z_{t+j}|z_{t-1}, x_{t-1}^m] \\ E[x_{t+j}^m|z_{t-1}, x_{t-1}^m, I_t] - E[x_{t+j}^m|z_{t-1}, x_{t-1}^m] \end{pmatrix} = K_m(\gamma)^j D_m(\gamma) I_t \tag{16}$$

where I_t is a vector of zeros that is augmented with a single entry equal to the size of the common policy shock, for which the impulse response is computed. Using the ordering from equation (8) and setting $I_t(1) = -0.01$ the sixth entry of $IR_{t+j}^1(\gamma;\eta^i)$ gives the impulse response of the output gap in the first model (NK_CGG99) to a surprise interest rate reduction of 1 percent. Similarly, the sixth entry of $IR_{t+j}^2(\gamma;\eta^i)$ gives the impulse response of the output gap in the second model (NK_RW97) to the same type of shock.

It is then straightforward to compare the impulse responses of common variables to common shocks across models and policy rules. Such a comparison provides interesting insights into the transmission channels of monetary policy. We define a metric s that measures the distance between two or more models for a given characteristic of economic time series like an impulse response function. For example, the difference in the cumulative sum of the response of the output gap to a monetary policy shock of -1 percent for the models NK_CGG99 $(m = 1)$ and NK_RW97 $(m = 2)$ is given by the sixth entry of:

$$s(\gamma, z) = \sum_{j=0}^{\infty} (IR^1_{t+j}(\gamma; \eta^i; z) - IR^2_{t+j}(\gamma; \eta^i; z)). \tag{17}$$

The index z is meant as a reminder that we can only compare the entries in the impulse response vector for the common variables, but not the model specific variables. For the two models we get $s(\gamma, 6) = -0.0399$ under the Taylor rule, that is when the policy parameters γ imply an inflation reaction coefficient of 1.5, an output gap reaction of 0.5 and no interest rate smoothing.

Other possible characteristics for comparison are unconditional variances and serial correlation functions. The unconditional contemporaneous covariance matrix V_0^m for $([z\ x^m]')$ is given by:

$$V_0^m = \sum_{j=0}^{\infty} {K_m}^j D_m \Sigma^m {D_m}' {K_m}^{j\prime} \tag{18}$$

The variance is defined by the implicit expression $V_0^m = K_m V_0^m {K_m}' + D_m \Sigma^m {D_m}'$ and is solved for with an algorithm for Lyapunov equations. Given V_0^m the autocovariance matrices of $([z\ x^m]')$ are readily computed using the relationship:

$$V_j^m = {K_m}^j V_0^m \tag{19}$$

Again, we can compute objects for comparison between models in terms of the unconditional variance or the serial correlations and cross-correlations of common variables. Then, suitable metrics for measuring the distance between two or more models may be calculated. For example, the absolute difference of the unconditional variance for the two models given by:

$$\omega = |V_0^1(z) - V_0^2(z)| \tag{20}$$

The sixth entry on the diagonal of ω constitutes the difference of the unconditional variance of the output gaps of the two simple New-Keynesian models considered.Its value is given by $\omega(6, 6) = 10.7919$.

It is straightforward to construct other metrics that measure the differences between the models. In section 4 of this paper, for example, we will also study autocorrelation functions of comparable variables in different models of the U.S. economy.

3 A data base of macroeconomic models

Implementing the approach to model comparison outlined in the preceding section on a broader scale requires an archive of benchmark models. Individual researchers may then expand this model data base by introducing new models and conducting comparative analysis. The data base that we have created includes many well-known empirically-estimated macroeconomic models. The models implemented as of May 2009 are summarized in **Table 6**. A more detailed overview of each model is provided in appendix B. The data base may easily be expanded. The description of the model comparison software in Appendix A also includes an explanation how to incorporate new models in the data base and augment them with comparable variables.[15]

Currently, the data base includes estimated and calibrated models of the U.S. economy and the euro area, as well as several multi-country models. Most but not all models could be classified as New Keynesian because they incorporate rational expectations, imperfect competition and wage or price rigidities. All models are dynamic, stochastic, general equilibrium (DSGE) models if the term general equilibrium is taken to refer to economy-wide models compared to models of a particular sector of the economy. Only a subset of the models could be characterized as monetary business cycle models where all behavioral equations are derived in a completely consistent manner from the optimization problems of representative households and firms. Many authors use the term DSGE model to refer to this particular class of models. Thus, our data base offers interesting opportunities for comparing policy implications of this class of models to a broader set of empirically estimated, dynamic, stochastic, economy-wide macro models. While most of the models assume that market participants form rational, forward-looking expectations, we have also included some models which assume little or no forward-looking behavior.[16] In our view, comparative analysis of these classes of models will be useful to evaluate recently voiced criticisms that the new models are rendered invalid by the experience of the world financial crisis.

The models are grouped in four categories in **Table 6**. The first category includes small, calibrated versions of the basic New-Keynesian model such as the two models discussed in section 2. These models concentrate on explaining output, inflation and interest rate dynamics. Some of them are calibrated to U.S. data. The model taken from Clarida, Gali, and Gertler (2002) is a two-country version of the basic New-Keynesian model.

The second category covers estimated models of the U.S. economy. It includes small models of output, inflation and interest rate dynamics such as Fuhrer and Moore (1995) and Rudebusch and Svenson (1999). Other models are of medium scale such as Orphanides and Wieland (1998) or the well-known models of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007) that fully incorporate recent advances in terms of microeconomic foundations. The data base includes the

[15] In the future, we plan to develop an interactive software that helps automate the process of including models that model authors have implemented in DYNARE.

[16] For example, the models of Rudebusch and Svensson (1999) and Orphanides (2003) are essentially structural VAR models with some restrictions on some of the coefficients. The ECB's Area-Wide Model is a medium-size structural model but with a relatively limited role for forward-looking behavior compared to the other structural, rational expectations models in the data base.

version of Christiano, Eichenbaum and Evans model estimated by Altig, Christiano, Eichenbaum and Linde (2004) because it contains other economic shocks in addition to the monetary policy shock studied by Christiano et al (2005). Because of complications in programming the informational timing assumptions on expectations in this model in DYNARE, two versions are included, one version for simulating the consequences of the monetary policy shock and the other version for simulating the consequences of the other economic shocks in the model. Furthermore, we have included an additional version of the Altig et al (2004) model used in Taylor and Wieland (2011) that omits the cost-channel of monetary policy .[17] The largest model of the U.S economy in the data base is the Federal Reserve's FRB-US model of Reifschneider et al. (1999). We have included a linearized version of this model with rational expectations that was previously used in Levin et al (2003).

The third category in **Table 6** covers estimated models of the euro area economy. Four of these models have been used in a recent study of robust monetary policy design for the euro area by Kuester and Wieland (2009): the medium scale model of Smets and Wouters (2003), two small models by Coenen and Wieland (2005) that differ by the type of staggered contracts inducing inflation rigidity, and a linearized version of the Area-Wide Model used at the ECB for forecasting purposes. In addition, we have included an estimated DSGE model of the euro area recently developed at the Sveriges Riksbank.

The fourth category includes estimated and calibrated models of two or more economies. Currently, the largest model in the data base is the estimated model of the G7 economies of Taylor (1993). The estimated model of Coenen and Wieland (2003) with rational expectations and price rigidities aims to explain inflation, output and interest rate dynamics and spill-over effects between the U.S.A., the euro area and Japan. The model of Laxton and Pesenti (2003) is a two-country model with extensive microeconomic foundations calibrated to the economies of the euro area and the Czech republic. The Federal Reserve's SIGMA model is similarly rich in microeconomic foundations. The parameters in the two-country version of this model from Erceg et al (2008) are calibrated to the U.S. economy and a symmetric twin.

[17] This version was created in Taylor and Wieland (2011) to evaluate the effect of this assumption in comparing the Altig et al (2004) model with the model of Smets and Wouters (2007) that features no such cost channel.

Table 6: MODELS CURRENTLY AVAILABLE IN THE DATA BASE

1. SMALL CALIBRATED MODELS		
1.1	NK_RW97	Rotemberg and Woodford (1997)
1.2	NK_LWW03	Levin et al. (2003)
1.3	NK_CGG99	Clarida et al. (1999)
1.4	NK_CGG02	Clarida et al. (2002)
1.5	NK_MCN99cr	McCallum and Nelson (1999), (Calvo-Rotemberg model)
1.6	NK_IR04	Ireland (2004)
1.7	NK_BGG99	Bernanke et al. (1999)
1.8	NK_GM05	Gali and Monacelli (2005)
1.9	NK_GK09	Gertler and Karadi (2009)
1.10	NK_CK08	Christoffel and Kuester (2008)
1.11	NK_CKL09	Christoffel et al. (2009)
1.12	NK_RW06	Ravenna and Walsh (2006)
2. ESTIMATED US MODELS		
2.1	US_FM95	Fuhrer and Moore (1995)
2.2	US_OW98	Orphanides and Wieland (1998) equivalent to MSR model in Levin et al. (2003)
2.3	US_FRB03	Federal Reserve Board model linearized as in Levin et al. (2003)
2.4	US_FRB08	linearized by Laubach (2008)
2.5	US_FRB08mx	linearized by Laubach (2008), (mixed expectations)
2.6	US_SW07	Smets and Wouters (2007)
2.7	US_ACELm	Altig et al. (2005), (monetary policy shock)
	US_ACELt	Altig et al. (2005), (technology shocks)
	US_ACELswm	no cost channel as in Taylor and Wieland (2011) (mon. pol. shock)
	US_ACELswt	no cost channel as in Taylor and Wieland (2011) (tech. shocks)
2.8	US_NFED08	based on Edge et al. (2008), version used for estimation in Wieland and Wolters (2011)
2.9	US_RS99	Rudebusch and Svensson (1999)
2.10	US_OR03	Orphanides (2003)
2.11	US_PM08	IMF projection model US, Carabenciov et al. (2008)
2.12	US_PM08fl	IMF projection model US (financial linkages), Carabenciov et al. (2008)
2.13	US_DG08	DeGraeve (2008)
2.14	US_CD08	Christensen and Dib (2008)
2.15	US_IAC05	Iacoviello (2005)
2.16	US_MR07	Mankiw and Reis (2007)
2.17	US_RA07	Rabanal (2007)
2.18	US_CCTW10	Smets and Wouters (2007) model with rule-of-thumb consumers, estimated by Cogan et al. (2010)
2.19	US_IR11	Ireland (2011)

3. Estimated Euro Area Models

3.1	EA_CW05ta	Coenen and Wieland (2005), (Taylor-staggered contracts)
3.2	EA_CW05fm	Coenen and Wieland (2005), (Fuhrer-Moore-staggered contracts)
3.3	EA_AWM05	ECB's area-wide model linearized as in Dieppe et al. (2005)
3.4	EA_SW03	Smets and Wouters (2003)
3.5	EA_SR07	Sveriges Riksbank euro area model of Adolfson et al. (2007)
3.6	EA_QUEST3	QUEST III Euro Area Model of the DG-ECFIN EU, Ratto et al. (2009)
3.7	EA_CKL09	Christoffel et al. (2009)
3.8	EA_GE10	Gelain (2010)

4. Estimated/Calibrated Multi-Country Models

4.1	G7_TAY93	Taylor (1993a) model of G7 economies
4.2	G3_CW03	Coenen and Wieland (2002) model of USA, Euro Area and Japan
4.3	EACZ_GEM03	Laxton and Pesenti (2003) model calibrated to Euro Area and Czech republic
4.4	G2_SIGMA08	The Federal Reserve's SIGMA model from Erceg et al. (2008) calibrated to the U.S. economy and a symmetric twin.
4.5	EAUS_NAWM08	Coenen et al. (2008), New Area Wide model of Euro Area and USA
4.6	EAES_RA09	Rabanal (2009)

5. Estimated Models of other Countries

5.1	CL_MS07	Medina and Soto (2007), model of the Chilean economy
5.2	CA_ToTEM10	ToTEM model of Canada, based on Murchison and Rennison (2006), 2010 vintage
5.3	BRA_SAMBA08	Gouvea et al. (2008), model of the Brazilian economy
5.4	CA_LS07	Lubik and Schorfheide (2007), small-scale open-economy model of the Canadian economy
5.5	HK_FPP11	Funke et al. (2011), open-economy model of the Hong Kong economy

4 Comparing monetary and fiscal policies across models: An example

We have created a computational platform that renders comparisons of impulse response functions of common variables in response to common shocks, comparisons of autocorrelation functions of common variables in response to model-specific shocks and systematic investigations of policy rules across models straightforward. This result may be described by paraphrasing Lucas (1980) as follows: *we have completed the task of writing a program (in MATLAB instead of FORTRAN) that will accept specific economic policy rules as common comparable input for multiple economic models and will generate as output a comparison across models of statistics describing the operating characteristics* *of time series we care about, which are predicted to result from these policies according to different economic models*. The computational platform utilizes DYNARE software for model solution.[18] New models may easily be introduced and compared to established benchmarks thereby fostering a comparative rather than insular approach to model building. A detailed description of the model comparison software is provided in **appendix A**.

The software implementation and model database discussed in the preceding section contain a generalized interest rate rule that allows for much richer specifications than equation (9). For the comparison exercise in this paper, we consider five parameterizations of this generalized rule that are taken from Taylor (1993b), Levin et al. (2003), Smets and Wouters (2007), Christiano, Eichenbaum and Evans (2005) and Gerdesmeier and Roffia (2004), respectively. The specific formulas are shown in **Table 7**.

Table 7: POLICY RULES

Taylor (1993b):	$i_t^z = \sum_{j=0}^{3} 0.38 p_{t-j}^z + 0.50 q_t^z + \eta_t^i$
Levin et al. (2003):	$i_t^z = 0.76 i_{t-1}^z + \sum_{j=0}^{3} 0.15 p_{t-j}^z + 1.18 q_t^z - 0.97 q_{t-1}^z + \eta_t^i$
Smets and Wouters (2007):	$i_t^z = 0.81 i_{t-1}^z + 0.39 p_t^z + 0.97 q_t^z - 0.90 q_{t-1}^z + \eta_t^i$
Christiano et al. (2005)	$i_t^z = 0.8 i_{t-1}^z + 0.3 E_t p_{t+1}^z + 0.08 q_t^z + \eta_t^i$
Gerdesmeier and Roffia (2004):	$i_t^z = 0.66 i_{t-1}^z + \sum_{j=0}^{3} 0.17 p_{t-j}^z + 0.10 q_t^z + \eta_t^i$

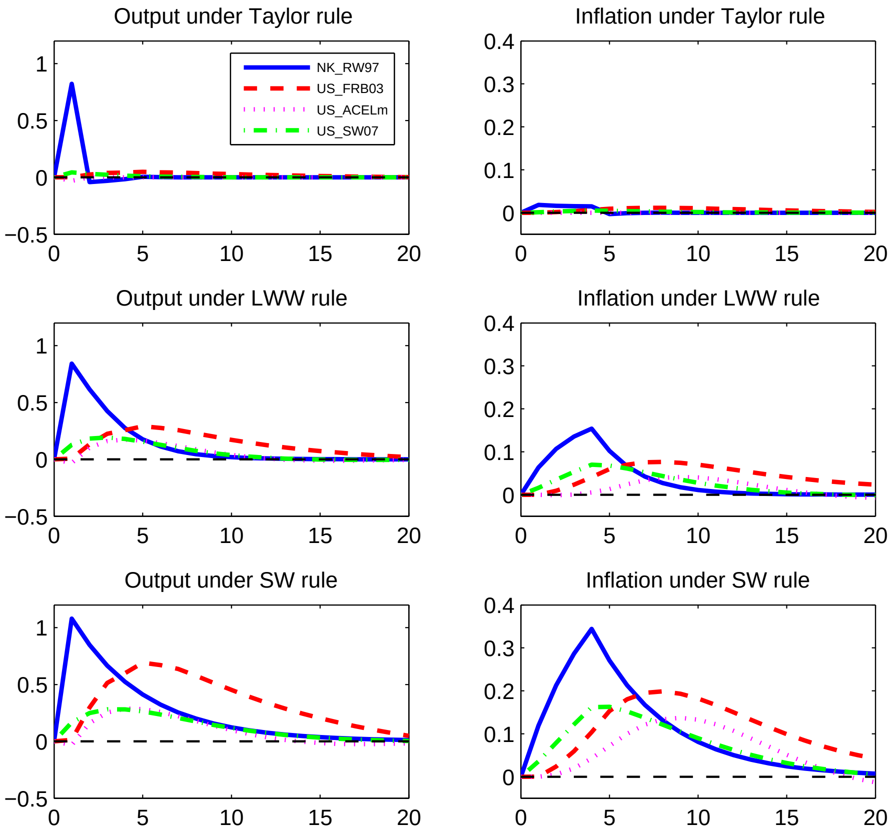
The first rule in the table, that is the simple monetary policy rule of Taylor (1993b) is well-known beyond academic economics and central banks for the following reasons. In the 1990s it became widely known that this rule described Federal Reserve interest rate decisions since 1987 surprisingly well. More recently, the large deviation of Federal Reserve policy from this rule between 2002 and 2006 has been cited as the source of cheap money fueling a housing bubble in the United States that ultimately triggered the world financial crisis. Perhaps little known is that Taylor (1993b) credits the comparison exercise of Bryant et al (1993) as the crucial testing ground that helped select this particular simple rule. Variations of the rule, motivated either by empirical estimation or model performance, abound in the literature. For comparison, we consider a rule originally estimated with U.S. data by Orphanides and Wieland (1998) and simulated in five models of the U.S. economy by Levin et al. (2003) (LWW). Their choice of models is included in our data base. The LWW rule

[18] It admits nonlinear as well as linear models and allows approximating nonlinear models with forward-looking variables with perturbation or two-point-boundary-value methods. For further information on DYNARE see Juillard (2001) and Juillard (1996).

allows for interest-rate smoothing and includes the lag of the output gap in addition to current inflation and the output gap that make up the Taylor rule. Smets and Wouters (2007) (SW) have estimated the same type of rule with interest smoothing, current inflation, current and past output gaps using Bayesian techniques together with the other structural parameters of their model model. Christiano, Eichenbaum and Evans (2005) consider a different policy rule that they attribute to Clarida, Gali and Gertler (1999). Their rule includes a response to the forecast of inflation rather than current inflation. It has also been studied in Taylor and Wieland (2011). Furthermore, we add a rule estimated with Euro area data. This rule is due to Gerdesmeier and Roffia (2004) and has been simulated in Kuester and Wieland (2009) in four models of the euro area economy that are also included in our data base.

Finally, the comparative approach to macroeconomic modeling and policy analysis is applied with several examples. We compare monetary and fiscal policy shocks under alternative monetary policy rules and investigate the predictions of different models and different policies for inflation and output persistence. **Figure 1** reports on the effect of a monetary policy shock on output and inflation in four different models of the U.S. economy under the Taylor rule, the LWW rule and the SW rule. The models considered are the calibrated New-Keynesian model of Rotemberg and Woodford (1997) from **Table 2** (NK_RW97, solid blue line), the Federal Reserve's FRB-US model from Levin et al. (2003) (US_FRB03, red dashed line), the model of Smets and Wouters (2007) (US_SW07, green dashed-dotted line) and the model of Altig et al. (2005) (US_ACELm, pink dotted line). The particular shock considered is a one time unexpected reduction of the nominal interest rate of 1 percentage point. Following the initial shock the nominal interest rate path corresponds to the prescriptions of the policy rule. Three rules are compared by the three rows of panels in **Figure 1**, the Taylor, LWW and SW rules.

Figure 1: NEGATIVE MONETARY POLICY SHOCK



The simulation results exhibit the following findings regarding the transmission of a monetary policy shock. All four models exhibit nominal rigidities and therefore indicate that a monetary shock affects real output as indicated by the left column of panels. Under the Taylor rule, the effect on output is short-lived. In three of the four models the effect is also very small. The exception is the simple calibrated New Keynesian model (NK_RW97) which indicates a sharp large but temporary boost to output. Under the LWW and SW rules the effect on real output in the US_SW07, US_ACELm and FRB_03 models builds up over time. The reason for the larger and longer-lasting effect on real output lies in the persistent effect of the shock on interest rates due to the near-unity reaction coefficient on the lagged interest rate in these two rules. In NK_RW97 the effect on real output remains sharp and large but also peters out more slowly. An interesting difference between FRB_03 and the other models is that the peak effect of the monetary shock on real output in FRB_03 is reached only in the second year but in the first year in the other models. Thus, the models that incorporate recent advances in microeconomic foundations contradict conventional policy maker wisdom regarding "long" policy lags of more than one year. The reason for this finding is that these models give more room to the possibility of forward-looking and optimizing behavior by households and firms. The effects of the monetary shock on real output in the two estimated DSGE models with microeconomic foundations are almost identical as already noted by Taylor and Wieland (2011).

The effects of a monetary policy shock on inflation (second column of panels) are more drawn out with the peak effect occurring later than the peak in output, typically in the second or third after the initial shock. Again, the results from the calibrated simple New-Keynesian model (NK_RW97) appear too extreme relative to the findings from the empirically-estimated models.

Figure 2: AUTOCORRELATION FUNCTIONS

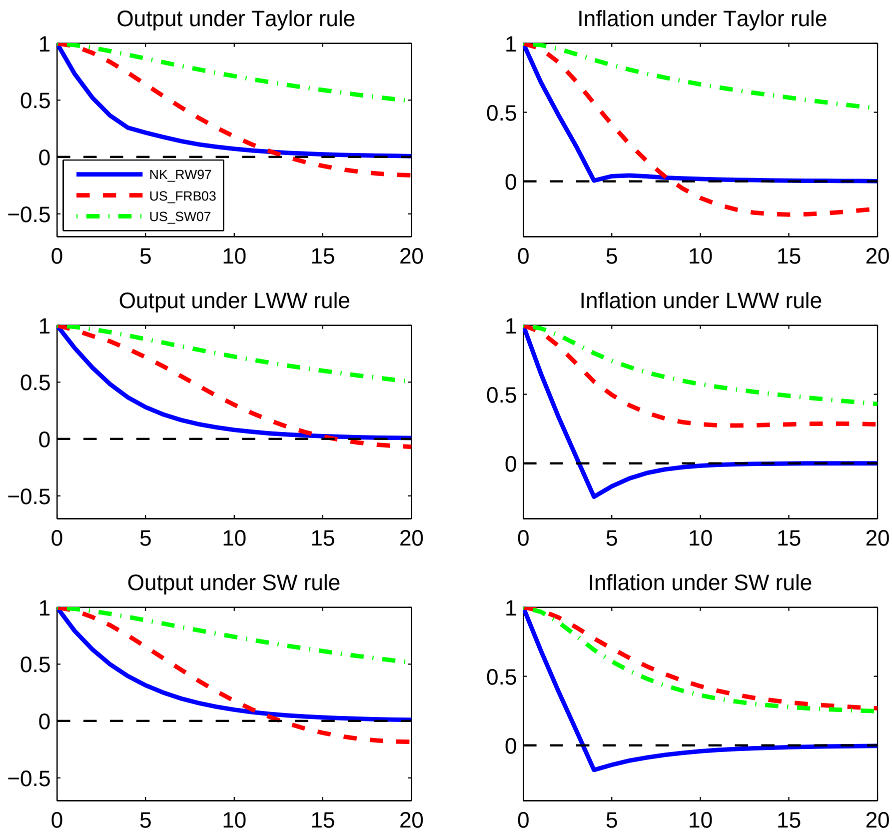


Figure 2 reports the autocorrelation functions of output and inflation under the Taylor, LWW and SW monetary policy rules. These time series characteristics are derived assuming that shocks are drawn from the empirical distribution of structural shocks of these models. Only the variance of the monetary policy shock is set to zero. The Altig et al. (2005) model is omitted from the comparison because the two non-monetary shocks in that model explain only a relatively small part of the

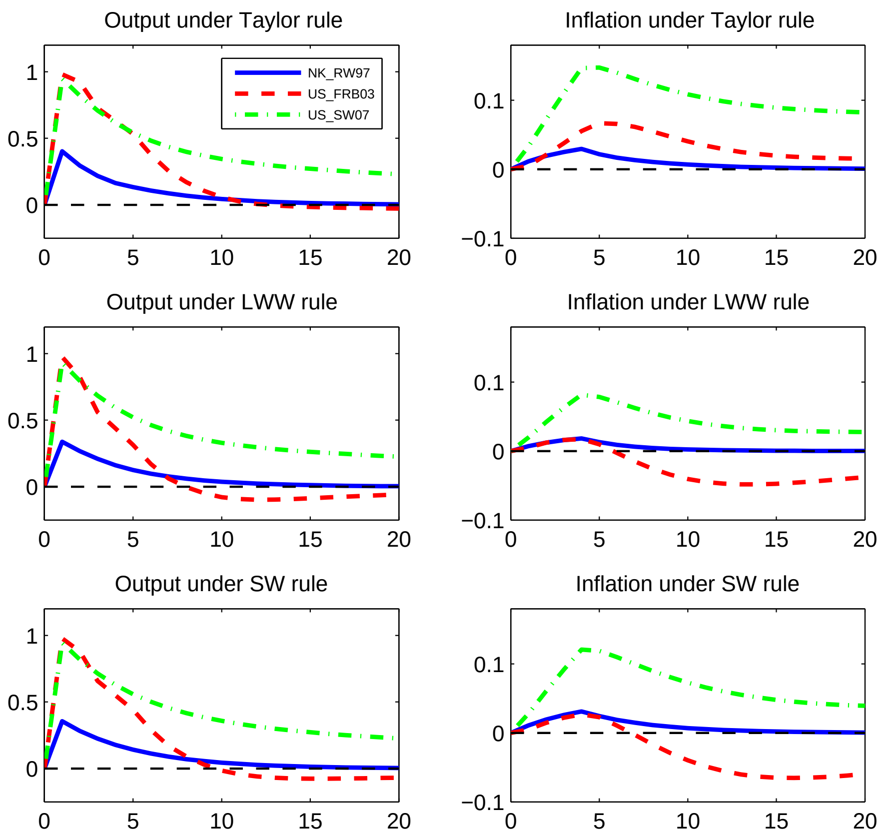
empirical output and inflation volatility in the U.S. economy (see Taylor and Wieland (2011)). The small calibrated New-Keynesian model (NK_RW97) exhibits the lowest degree of output and inflation persistence among the three remaining models whichever policy rule is considered. As discussed in section 2 this model does not allow for lagged terms of inflation and output in the New-Keynesian IS and Phillips curves. Only, the exogenous shocks exhibit persistence in that model. The Federal Reserve's estimated model of the U.S. economy, however, implies a larger degree of output and inflation persistence. Thus, better empirical fit is obtained by allowing for a richer set of dynamics and adjustment costs that imply the appearance of one or more lags of endogenous variables in key behavioral equations.

A rather surprising finding is that the estimated DSGE Model of Smets and Wouters (2007) exhibits the highest degree of output persistence under all three policy rules, even under the SW rule that is estimated along with the model. One might have expected that this model with microeconomic foundations would lie somewhere in between the small calibrated model of Rotemberg and Woodford (1997) and the FRB-US model. Much criticism of models such as the Federal Reserve's model was that they introduce too many adjustment costs and therefore too much endogenous persistence. Given our findings one might therefore suspect that Smets and Wouters (2007) have built in too much persistence in their model, a criticism recently voiced by Chari, Kehoe and McGrattan (2009). It would be of interest to further investigate the sources of persistence in this model in future work.

Next, we turn to an evaluation of the consequences of a government spending shock of 1 percent of GDP in the three models. The fiscal policy rule for discretionary government spending is defined as in section 2 by equation (10) with a coefficient γ_g of unity. The estimated degree of persistence of such a shock to government spending differs in each model. Its implications for output and inflation are shown in **Figure 3**. In all three models, the initial shock causes output to increase in the same quarter, followed by a slow drawn-out decline over subsequent years. This profile holds under all monetary policies considered. The magnitude of the effect is rather similar for the monetary rules considered, but differs a lot across models. The impact effect is smallest in the small New-Keynesian model around 0.4 percent of output, compared to about 1 percent of output in the other two models. Thus, private consumption and investment are crowded out immediately in the small model. In the other two models, private consumption and investment also decline from the start but more slowly. Somewhat surprisingly, output declines faster and inflation increases less in the US_FRB03 model than in the US_SW07 model.

Comparative evaluations of the consequences of fiscal policy and the robustness of policy recommendations for fiscal stimulus are particularly urgent given the amount of resources to such measures recently. Cogan et al. (2009) provide a first assessment of the American Recovery and Reinvestment of 2009. Their analysis based the Smets and Wouters (2007) model and the Taylor (1993) model from this data base suggests that the estimates of fiscal multipliers implied by government advisers (cf. Romer and Bernstein (2009)) are far too optimistic and not robust to model uncertainty. The simulation in **Figure 3** suggests that an evaluation using the US_FRB03 model with rational expectation would result in similar conclusions, while the NK_RW97 model would provide an even more pessimistic assessment. Interestingly, the US_FRB03 considers different components of government spending such as federal versus state expenditures and government consumption versus government investment. The shock simulated here is spread across all components according to their steady-state shares in total government spending. Further studies evaluating the non-linear timing and anticipation effects of such fiscal stimulus packages highlighted by Cogan et al (2009) would also be of interest.

Figure 3: FISCAL POLICY SHOCK



5 Conclusion

This paper provides a new comparative approach to model-based research and policy analysis that enables individual researchers to conduct model comparisons easily, frequently, at low cost and on a large scale. Using this approach a model archive is built that includes many well-known empirically estimated models that may be used for quantitative analysis of monetary and fiscal stabilization policies. A computational platform is created that allows straightforward comparisons of models' implications. Its application is illustrated by comparing different monetary and fiscal policies across selected models. Researchers can easily include new models in the data base and compare the effects of novel extensions to established benchmarks thereby fostering a comparative instead of insular approach to model development. Wide application of this approach could help dramatically improve the replicability of quantitative macroeconomic analysis, reduce the danger of circular developments in model-based research and strengthen the robustness of policy recommendations.

In light of the experience of the global financial crisis, it would be very useful to extend the coverage of the model data base for future policy robustness evaluations. In the words of ECB President Trichet, *" we need to better integrate the crucial role played by the financial system into our macroeconomic models, ... we may need to consider a richer characterisation of expectation formation, ... We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents, (and) we need to entertain alternative motivations for economic choices".* Thus, we would propose a major research effort to include the following modeling approaches for direct comparison: (i) DSGE models with more realistic treatments of banking and financial risks, (ii) models that deviate from the standard assumption of rational expectations by including imperfect information, learning and heterogeneous beliefs, (iii) models that allow for deviations from the basic microeconomic assumption of rational optimizing behavior by households and firms. This proposal is laid out in more detail in Wieland (2011).

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