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Abstract

DSGE (Dynamic stochastic general equilibrium) models are the common workhorse of modern macroeconomic theory. Whereas story-telling and policy analysis were in the forefront of applications since its inception, the forecasting perspective of DSGE models is only recently topical. In this study, we perform a post-mortem analysis of the predictive power of DSGE models in the case of Austria's Great Recession in 2009. For this purpose, eight DSGE models with different characteristics (small and large models; closed and open economy models; one and two-country models) were used.

The initial hypothesis was that DSGE models are inferior in ex-ante forecasting a crisis. Surprisingly however, it turned out that not all but those models which implemented features of the causes of the global financial crisis (like financial frictions or interbank credit flows) could not only detect the turning point of the Austrian business cycle early in 2008 but they also succeeded in forecasting the following severe recession in 2009.

In comparison, non-DSGE methods like the ex-ante forecast with the Global Economic (Macro) Model of Oxford economics and WIFO's expert forecasts performed not better than DSGE models in the crisis.

Keywords: DSGE models; business cycles; forecasting; open-economy macroeconomics.
JEL Classification: C11, C32, C53, E32, E37.

Contents

1. Introduction

It is common knowledge that the economic community was not able to forecast the Great Recession in 2009. The crisis evolved in a sequence of crises (see Breuss, 2016): it started with the US subprime crises, followed by a banking crisis triggered by the Lehman Brothers' crash on 15 September 2008 which induced a collapse of the interbank market. Then the stock market plunged and caused the Great Recession in 2009. Starting in the United States it spread to most industrial countries. Europe, in particular the Euro area generated its unique "Euro (debt) crisis". As an excuse one argued that because of the specificity of the crisis, the economic models then used were not able to forecast it.

In the forecasting business, a variety of models are used, but primarily traditional macro econometric models. The now common workhorse of modern macroeconomic theory, however, are DSGE (Dynamic stochastic general equilibrium) models[1]. They are used to predict (forecast) and explain (story-telling) co-movements of aggregate time series over the business cycle (real business cycle theory) and to perform policy analysis (policy experiments: IRF implications of shocks of fiscal and monetary policy and of technical change). Whereas the two latter applications were in the forefront of applications since its inception, based on the work by Kydland and Prescott (1982)[2], the forecasting perspective is only recently topical.

Most forecasting evaluations with DSGE models so far were executed for the US economy and for the Euro area (at the ECB). In the following we perform a post-mortem of DSGE model forecasts of the Great Recession (2009) in Austria. For this purpose, we use eight DSGE models with different characteristics (closed and open economy models; one and two-country models). Primarily, the development of the Austrian real GDP during the Great Recession of 2009 and thereafter is evaluated ex-ante with out-of-sample forecasts.

The next chapter describes briefly the DSGE models used for this forecasting exercise. In the third chapter, first we give a short overview of DSGE forecasting attempts in the literature. Then the forecasting performance of the different models for Austria is evaluated. Additionally, in the fourth chapter we check the forecasting performance of non-DSGE methods (Global Economic (Macro) Model of Oxford Economics and WIFO's expert forecasts). Conclusions are drawn in the last chapter.

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[1] Although DSGE modelling is mainstream in modern macroeconomics, there are many critics of DSGE modelling. Blanchard (2016) questions the future of DSGE models as a proper instrument of modern macroeconomics. Romer (2016) fundamentally criticises the flaws of DSGE models in properly explaining the fluctuations of economic development.

[2] A short history of DSGE modelling can be found in Fernández-Villaverde (2010).

2. DSGE Models applied to the Austrian Business Cycle

DSGE models are micro founded, based on optimizing agents: consumers and firms maximizing utility and profits respectively. Technology drives output via a production function. Institutions (fiscal and monetary) are modelled by budget constraints and some policy rule (e.g. Taylor rule). At present there exist two competing schools of DSGE modelling which end in a synthesis:

- Real business cycle (RBC) theory of neoclassical growth models with flexible prices. Real shocks cause business cycle fluctuations[3]. The fathers of RBC models are Kydland and Prescott (1982).
- New Keynesian DSGE models (NK) build on a structure similar to RBC models, but assume that prices and wages are set by monopolistically competitive firms, adjusting not instantaneously and costlessly (price and wage rigidity). The first who introduced this framework were Rotenberg and Woodford (1997).
- New Keynesian Synthesis (NKS) models[4]. Goodfriend and King (1997) and Clarida, Gali and Gertler (1999) introduced a framework mixing RBC features with nominal and real rigidities.

Under the basic assumption that theoretical DSGE models are micro founded, they should describe any market economy, not only that for which the model was originally designed. For this reason, we use DSGE models originally applied for other countries (USA, Portugal, Euro Area etc.) to track the development of Austrian macroeconomic data.

In empirical work[5], DSGE models are frequently estimated with Bayesian methods, in particular if the goal is to track and forecast macroeconomic time series (e.g. GDP, consumption, investment, prices, wages, employment and interest rates). Bayesian inference delivers posterior predictive distributions that reflect uncertainty about latent state variables, parameters, and future realizations of shocks conditional on the available information.

We use two kinds of techniques to estimate the following DSGE models for Austria:

[3] A basic RBC DSGE model with monopolistic competition can be found in Griffoli (2013), pp. 11-14.

[4] Poutineau et al. (2015) demonstrate the working of a NKS DSGE model using the benchmark "New Keynesian 3-equation Model" consisting of a New Keynesian Phillips curve (inflation), a dynamic IS curve (output) and a monetary policy (Taylor) rule (interest rate).

[5] Fernández-Villaverde (2010) calls the research of formal estimation of DSGE models (the cornerstone of modern macroeconomics) - the combination of rich structural models, novel solution algorithms, and powerful simulation techniques - which allows researchers to transform the quantitative implementation of equilibrium models from ad hoc procedures to a systematic discipline, the *New Macroeconometrics*.

- Dynare with Matlab[6]; and
- YADA (Yet Another DSGE Application) is a Matlab program for Bayesian estimation and evaluation of DSGE models (see, Warne, 2015)

The DSGE models, used here are estimated with Austrian quarterly data from the early nineties up to 4Q2016. The primary database is those of Oxford Economics.

2.1 Small and Medium-sized Closed and Open Economy Models

We start with a small closed economy DSGE model and then advance to more complex models (see the overview in Table 1).

Table 1: DSGE Models Estimated with Austrian Data

Authors	Characteristics					
	Coun-tries	**Origi-nally applied**	**Model Size Small/**	**Eco-nomy**	**Endo-genous**	**Special**
	No	**in**	**Medium/ Large**	**Closed/ Open**	**Vari-ables**	**Fea-tures**
An-Schorfheide (2007)	1	USA	Small	Closed	3	NK
Lubik-Schorfheide (2007)	1	USA	Small	Open	5	NK+EX
Smets-Wouters (2007)	1	USA	Medium	Closed	7	NK
Del Negro-Schorfheide (2013)	1	USA	Medium	Closed	8	SW+FF
Christoffel-Coenen-Warne (2008)	1	NAWM (EA)	Large	Open	18	NK
Poutinau-Vermandel (2015)	2	Core+Periphery EA	Large	Open	15	EA+IBF
Almeida (2009)	1	Portugal	Large	Open	13	NK
Breuss-Rabitsch (2009)	2	Austria+EA	Large	Open	17	NK

NK = New Keynesian DSGE model; EX = Exchange rate; SW = Smets and Wouters DSGE model; FF = Financial Frictions (Financial accelerator); NAWM = the New Area-Wide Model of the Euro Area; EA = Euro Area; IBF = International Bank Loan Flows.

A Small Closed Economy 3-equation DSGE Model:

The simplest possible example of a DSGE model[7] is the "Baby" DSGE model of An and Schorfheide (2007)[8]. With this small benchmark monetary policy analysis model, the authors studied monetary policy aspects of the USA. The theoretical economy in the An and Schorfheide model consists of a final goods producing firm, a continuum of intermediate goods producing firms, a representative household, and a monetary and a fiscal authority. It has six equations describing the behaviour of output, consumption, government spending, technology, inflation, and a short term nominal interest rate (Taylor rule). When substituting

[6] See Griffoli (2013) and the DYNARE website: http://www.dynare.org/

[7] Another similarly simple model would be the "New Keynesian 3-equation Model" presented by Poutineau et al. (2015).

[8] A short description of the An and Schorfheide model can be found in Warne (2015).

consumption and government spending into the output equation and technology into the Euler consumption equation the model reduces to three endogenous variables (GDP, inflation and interest rate). Three shocks (fiscal, monetary and productivity) are applied. Except of the interest rate, all variables are detrended. The measurement equation linking the data on quarter-to-quarter GDP growth (differences of the natural logarithm, annualized quarter-to-quarter inflation rates, and annualized nominal interest rates. The model is estimated in YADA and Austrian data over the period 1Q1992 to 4Q2016.

A Small Open Economy DSGE Model:

Lubik and Schorfheide (2007)[9] extended the closed economy An and Schorfheide model to a small open economy DSGE model. It consists of a forward-looking IS-equation and a Phillips curve. Monetary policy is also given by a Taylor-type interest rate rule, where the exchange rate is introduced via the definition of consumer prices and under the assumption of PPP. The model uses five shocks (three shocks of the An and Schorfheide model) plus two external shocks (foreign GDP and foreign inflation). In log-linearized form the model is estimated in YADA and with Austrian data over the period 1Q1999 to 4Q2016.

The Most Cited DSGE Model of a Closed Economy:

A well-known example of a medium-sized DSGE model is that of Smets and Wouters (2007)[10]. Although the authors study shocks and frictions in US business cycles the model is designed for a closed economy. The Smets and Wouters (SW) model uses basically a sticky price and wage system, followed by a flexible-price based output gap measure in the monetary policy rule.

The SW model is consistent with a balanced steady-state growth path driven by deterministic labour augmenting technological progress. The observed variables are given by quarterly data of the log of real GDP per capita, the log of real consumption per capita, the log of real investment per capita, the log of hours per capita, the log of quarterly GDP deflator inflation, the log of real wages, and the federal funds rate (in the application for Austria, ECB's Main Financing Operations (MFO) interest rate). All observed variables except hours, inflation, and the MFO rate is measured in first differences of the natural logs. Consistent with the number of endogenous variables, the SW model uses seven shocks to describe the business cycle development: shock to fiscal, monetary, consumption, investment, technology, inflation and

[9] A short description of the Lubik and Schorfheide model can be found in Warne (2015).
[10] A short description of the Smets and Wouters model can be found in Warne (2015).

wages. The model is estimated in YADA with Austrian data over the period 1Q1995 to 4Q2016.

The SW DSGE Model with Financial Frictions;

Del Negro and Schorfheide (2013)[11] presents a small-scale version of the Smets and Wouters model by removing several features, such as capital accumulation. It is also assumed that there is no wage stickiness in the small-scale model. Consequently, the marginal cost is equal to the real wage, and the latter is equal to the marginal rate of substitution between consumption and leisure. In addition, Del Negro and Schorfheide (2013) introduce financial frictions into their variant of the SW model based on the financial accelerator approach of Bernanke, Gertler, and Gilchrist (1999). The set of measurement equations is augmented by an equation explaining the spread of Moody's seasoned Baa corporate bond yield spread over the 10-year treasury note yield at constant maturity by the interest rate difference (real interest rate minus real rent on capital). In the Del Negro and Schorfheide model the eight endogenous variables are driven by eight shocks: In addition to the seven shocks in the SW model, one financial shock is introduced. In the estimation for Austria, the spread is measured by the 10-year Austrian government bond yield over those of Germany. The model is estimated in YADA with Austrian data over the period 1Q1992 to 4Q2016.

2.2 Large Open Economy Models

The NAWM DSGE Model for the Euro Area:

In the following we describe large-sized open economy DSGE models, used to estimate the Austrian business cycle. These models should be able to better track the development of the Austrian economy than small and often closed economy DSGE models.

Christoffel, Coenen and Warne (2008), authors at the European Central Bank (ECB) designed the "The New Area-Wide Model (NAWM) of the Euro Area", a micro-founded open-economy DSGE model. The NAWM is for use in the (Broad) Macroeconomic Projection Exercises regularly undertaken by ECB/Eurosystem staff and for policy analysis. The NAWM is neo-classical in nature and centred around intertemporal decisions of households and firms which are maximising expected life-time utility and the expected stream of profits, respectively.

The NAWM models the domestic economy (the Euro area) existing of four types of economic agents: households, firms, a fiscal authority, and a monetary authority (Taylor rule). Firms are

[11] A short description of the Del Negro and Schorfheide model can be found in Warne (2015).

distinguished between producers of tradable differentiated intermediate goods and producers of three non-tradable final goods: a private consumption good, a private investment good, and a public consumption good. In addition, there are foreign intermediate-good producers that sell their differentiated goods in domestic markets, and a foreign retail firm that combines the exported domestic intermediate goods. International linkages arise from the trade of intermediate goods and international assets, allowing for limited exchange-rate pass-through on the import side and imperfect risk sharing.

The NAWM consist of 18 endogenously explained macro-economic variables (GDP, private consumption, government consumption, investment, employment, wages, interest rate, effective exchange rate, exports, imports, foreign demand, foreign prices, inflation (GDP and consumption deflator), foreign interest rate, export prices of competitors, import deflator, oil prices). These 18 variables are driven by the same number of shocks. For our exercise the model is estimated with Austrian data in YADA over the period 1Q1995 to 4Q2016.

A Two-Regions Euro Area DSGE Model with Banking:

Poutineau and Vermandel (2015) develop a two-country DSGE model to document how the transmission of asymmetric shocks in the Eurozone has been affected with a banking system that provides cross-border interbank and corporate lending facilities. This solution is original with respect to the existing literature of monetary policy issues in a monetary union. The authors react with their specification on missing elements in pre-crisis models by considering phenomena which have contributed to the GFC 2008, the Great Recession 2009 and the following Euro crisis. The two-country model considers EMU (the Euro area) as consisting of two regions: the periphery and the core. The number of shocks is higher (or equal) to observable variables (15) to avoid stochastic singularity issue

We estimate this DSGE model with 15 endogenous variables for a two-country setting (Austria and Euro Area) in Dynare over the (Euro area) period 1Q1999 to 4Q2016.

A NK DSGE Model for Portugal:

Almeida (2009) developed a New-Keynesian DSGE model for a small open economy integrated in the Economic and Monetary Union (EMU of the EU), estimated for the Portuguese economy, using a Bayesian approach. The model features five types of economic agents namely households, firms, aggregators, the rest of the world and the government. It is assumed that monetary policy is decided by the ECB and that the domestic economy's size is negligible, relative to those of the EMU, and therefore Portugal cannot influence EMU’s

economy but the EMU is determining Portugal's business cycle. The model contains 13 endogenous variables with the same number of shocks.

This prototype model for a small member of the Euro area should also fit well for the Austrian economy. The estimation of this DSGE model with Austrian data (13 endogenous variables) is executed in Dynare over the period 1Q1995 to 4Q2015.

A Two-Country DSGE Model of Austria and the Euro Area:

Breuss and Rabitsch (2009) were the first to model a DSGE model for Austria. Although the approach is theoretically similarly to those of the SW model, its novel feature consists in modelling a two-country DSGE model. It is a DSGE model in the style of New Keynesian/New Open Economy Macroeconomics for the small open economy of Austria as a member of the European Economic and Monetary Union (EMU)[12]. The model was originally estimated using Bayesian methods on quarterly data covering the period of 1Q1975-1Q2005. Because Austria entered the EMU on 1 January 1999 we considered this regime switch by partitioning into two periods: a pre-EMU and a post-EMU period. For our purpose, the evaluation of the forecast quality in the Great Recession 2009 we re-estimated the model (with 17 endogenous variables and an equal number of shocks) from 1Q1995 to 4Q2015. The estimation is executed in Dynare with Austrian and Euro area data.

3. Which DSGE Model Wins the Trophy?

DSGE models serve three purposes: They are used to predict (forecast) and explain (story-telling) co-movements of aggregate time series over the business cycle (real business cycle theory) and to perform policy analysis (policy experiments[13]: IRF implications of shocks of fiscal and monetary policy[14] and of technical change). Whereas the two latter applications were in the forefront of applications since its inception, the forecasting perspective is only recently topical.

Before presenting the results of the post-mortem of DSGE model forecasts of the Great Recession in Austria, we give a short literature review of recent attempts to put DSGE models to the test in forecasting normal business cycles and crises.

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[12] A three-country version (Austria, Euro area and USA) of this NK DSGE model was developed in Breuss and Fornero (2009).

[13] A recent example is the analysis of the implication of the EU-Banking Union with the DSGE model QUEST of the European Commission (2 two-regions Euro area model) by Breuss et al (2015).

[14] Volker Wieland (see Wieland et al., 2012) heads an EU-sponsored project of DSGE model comparison to analyse fiscal and monetary policy shocks under different rules, executed with a common algorithm. The models used are collected in "The Macroeconomic Model Database (MMB)" (see the MMB-Website: http://www.macromodelbase.com/download/).

3.1 Forecasting with DSGE Models

DSGE models are widely applied in academic research but also in international institutions (European Commission, IMF, ECB), in particular in central banks. More and more DSGE models are also used for forecasting purposes[15]. The literature so far dealt firstly with general aspects of the forecasting performance of DSGE models and with comparisons with other times series techniques (mostly VARs and BVARs), in recent attempts the predictive power of DSGE models were applied to understand the GFC 2008/09[16]. The hitherto forecasting exercises were concentrated on the USA and the Euro area.

USA:

The forecasting exercise of Del Negro et al. (2007) is an early attempt to evaluate the forecasting quality of DSGE models. First, they develop a set of tools that is useful for assessing the time series fit of a DSGE model. They systematically relax the implied cross coefficient restrictions of the DSGE model to obtain a VAR specification that is guaranteed to fit better than the DSGE model. Then they use this specification as a benchmark to characterize and understand the degree of misspecification of the DSGE model. Second, they apply these tools to a variant of the model of Smets and Wouters and document its fit and forecasting performance based on postwar U.S. data over the period 2Q1974 to 1Q2004.

The first comprehensive analysis of the forecasting capability of DSGE models during the Great Recession 2009 in the USA is done by Del Negro and Schorfheide (2013). They demonstrate the forecasting performance of the Smets and Wouters (2007) DSGE model with data up to 2011, compare it with professional forecasts published in the "Blue Chip" survey and the forecasts by the Federal Reserve Board of Governors (the so-called "Greenbook"), and show how it changes as they augment the standard set of observables with external information from surveys (nowcasts, interest rates, and long-run inflation and output growth expectations). They also explore methods of generating forecasts in the presence of a zero-lower-bound constraint on nominal interest rates and conditional on counterfactual interest rate paths. Lastly, the authors perform a post-mortem of DSGE model forecasts of the Great Recession in the USA, and show that forecasts from a version of the SW model augmented by financial frictions and with interest rate spreads as an observable compare well with Blue Chip forecasts.

[15] For a literature review, see Del Negro and Schorfheide (2013), p. 35

[16] A critical assessment of the usefulness of theory-base forecasts with estimated DSGE models can be found in Giacomini (2015).

The three DSGE models used by the authors to rationalize ex-post the 2008-09 recession in the USA do not perform better than the Blue Chip and the Greenbook forecasts. Similar results are reached in the post-mortem analysis of the Great Recession. The examination of DSGE model forecasts during the 2008-09 US recession suggests that the DSGE models with financial frictions are preferable to the original SW model.

Kolasa and Rubaszek (2014) compare the quality of forecasts from DSGE models with and without financial frictions. The exercise is done for the US economy with data, covering the period 1Q1970 to 4Q2010. They find that accounting for financial market imperfections does not result in a uniform improvement in the accuracy of point forecasts during non-crisis times while the average quality of density forecast even deteriorates. In contrast, adding frictions in the housing market proves very helpful during the times of financial turmoil, over performing both the frictionless benchmark and the alternative that incorporates financial frictions in the corporate sector.

Merola (2014) analyses ex-post the relevant factors for the recent banking crisis of the US economy in 2008. The analysis is done by comparing the original Smets and Wouters model (2007) with an alternative version augmented with the financial accelerator mechanism à la Bernanke, Gertler and Gilchrist (1999). Both versions are estimated using Bayesian techniques over the sample period: 1967 to 2012. The Smets and Wouters model, augmented with the financial accelerator mechanism, is suitable to capture much of the historical developments in U.S. financial markets that led to the financial crisis. The model can account for the output contraction in 2008, as well as the widening in corporate spreads and supports the argument that financial conditions have amplified the U.S. business cycle and the intensity of the recession.

Euro area:

Christoffel, Coenen and Warne (2011) make n-step ahead and out-of-sample forecasts for the Euro area with the NAWM and compared its performance with vector autoregressions (VARs), Bayesian vector autoregressions (BVARs), a random walk, and a location parameter, namely the mean. The out-of-sample forecast evaluation exercise covers the period after the introduction of the euro up to the pre-crisis year 2006. Overall, the results suggest that the NAWM performs quite well when compared with the reduced-form forecasting tools. In particular, the model compares favourably when forecasting real GDP growth, the trade variables, employment, the real exchange rate, and the short-term nominal interest rate.

However, the NAWM is less successful when forecasting certain nominal variables, e.g. nominal wage growth.

Smets et al. (2013) analyze the real-time forecasting performance of the New Keynesian DSGE model of Galí, Smets, and Wouters (2012) estimated on Euro area data. They investigate to what extent forecasts of inflation, GDP growth and unemployment by professional forecasters improve the forecasting performance over the period 1Q1999 to 4Q2010. The authors consider two approaches for conditioning on such information. Under the "noise" approach, the mean professional forecasts are assumed to be noisy indicators of the rational expectations forecasts implied by the DSGE model. Under the "news" approach, it is assumed that the forecasts reveal the presence of expected future structural shocks in line with those estimated over the past. The forecasts of the DSGE model are compared with those from a Bayesian VAR model and a random walk. Overall, the authors find that the GSW model outperforms the random-walk model and has similar performance as the non-structural BVAR model. Adding one to two-year-ahead professional forecasts of real GDP growth, inflation, and the unemployment rate does not significantly improve the overall performance of the GSW model, although it does help to reduce some of the bias in the forecasts of wage growth in the news models.

3.2 DSGE Model Scores Forecasting Austria's Great Recession

In the following we examine ex-ante (or out-of-sample[17]) forecasts of Austria's Great Recession in 2009 with the models described in Table 1. The forecasts of real GDP growth are obtained at two different junctures of the crisis that lead to the recession:

(i) *Before the default of Lehman Brothers (bLB)*. The models are estimated until 1Q2008 (the peak of the business cycle) and the out-of-sample forecasts run from 2Q2008 to 4Q2016.

(ii) *After the default of Lehman Brothers (aLB).* The models are estimated until 3Q2008 (the peak of the business cycle) and the out-of-sample forecasts run from 4Q2008 to 4Q2016.

Out-of-sample forecast can be executed conditional[18] on specific knowledge at the inception of a crisis or unconditional (without side knowledge). In the following we evaluate the models with unconditional forecasting methods. In our analysis, we take the mean forecasts[19].

[17] The ex-post or within-sample forecast of the eight DSGE models used to capture the business cycle in Austria can be found in the Annex.

[18] Conditional forecasting concerns forecasts of endogenous variables conditional on a certain path and length of path for some other endogenous variables. This is important when one uses real-time data vintages. The

The forecasting quality of the DSGE models during the Great Recession and thereafter are evaluated with the measure Root Mean Square Error (RMSE). Because the DSGE model we use have different measures of GDP (mostly the annualized growth rate of real GDP, but some use also GDP Gaps) we take the normalized RMSE (NRMSE is defined in the footnote of Table 2) to be able to compare the forecasting performance of the different models. The results are collected in Table 2.

Table 2: Forecasting Performance of DSGE models compared with Macro models in the Great Recession 2009
Out-of-Sample Forecast Performance of the Austrian real GDP

Model type	NRMSE					
	Great Recession 2009*				Great Recession 2009-2016*	
	Before LB	**TP**	**After LB**	**TP**	**Before LB**	**After LB**
DSGE Models:						
An-Schorfheide (2007)	0.4207	yes	**0.6210**	yes	0.3146	0.3856
Lubik-Schorfheide (2007)	0.4969	no	0.3743	yes	0.2596	0.2101
Smets-Wouters (2007)	0.2883	yes	0.2681	yes	0.1897	0.1811
Del Negro-Schorfheide (2013)	0.3267	no	0.2931	yes	**0.1659**	**0.1659**
Christoffel-Coenen-Warne (2008)	0.6528	no	0.3205	yes	0.3423	0.2472
Poutinau-Vermandel (2015)	**0.2792**	yes	**0.2102**	yes	0.2298	0.1668
Almeida (2009)	0.3000	yes	0.3342	yes	**1.8176**	**0.6096**
Breuss-Rabitsch (2009)	**0.8811**	yes	0.3986	yes	1.1101	0.4669
Global Economic (Macro) Model:						
Oxford Economics (OEF)	0.4537	no	0.2920	yes	0.2946	0.2001

NRMSE = Normalized RMSE = RMSE/(Xmax-Xmin); X = observed variable.
* DSGE models: *Before Lehman Brothers (bLB)* = estimation until 1Q2008; out-of-sample forecast (OoS) = 2Q2008-4Q2016; *After LB* (aLB) = estimation until 3Q2008; OoS forecast = 4Q2008-4Q2016;
OEF Macro model: Before LB = Database March 2008; After LB = Database November 2008.
TP = detected turning point (from 1Q2008 to 2Q2008).
NRMSE is calculated in the period "Great Recession 2009" over the period 1Q2008-4Q210, in the period "Great Recession 2009-2016" over the period 1Q2008-4Q2016.
Bold = worst performing (major deviations of forecasts from reality); bold plus underline = best performing forecast (least error) in the Great Recession.

values for all observed variables for period *T*, the last "historical" time period, have often not been released by the statistical authority yet and are therefore missing from the relevant data vintage, i.e., the data set is *unbalanced*. Accordingly, some of the time *T* values need to be forecasted and the forecasts of these variables need to take into account that values for other variables are available for the same time period (see Warne, 2015, p. 173).

[19] The ex-ante forecasts of the eight models also show the confidence intervals (from 50% to 90%). In some cases, where the mean forecast results bLB and aLB are very close, there may be no significant difference in both forecast. Candidates for this conjecture would be the outcome of the well performing models of Smets and Wouters, Del Negro and Schorfheide as well as Poutineau and Vermandel.

The common interpretation of the causes of the past crisis is that it started with a sub-prime housing crisis, leading to a financial (banking) crisis in the USA (default of Lehman Brothers on 15 September 2008) and spread then globally to a global financial crisis and a Great Recession in 2009 (see Breuss, 2016). The Austrian economy was hit primarily by external forces via trade and capital movements. Of course, the shock of Lehman Brothers led also to a freeze of interbank lending. However, in contrast to the USA as well as Ireland and Spain Austria had no housing crisis.

Austria is a prototype of a small open economy. Therefore, models designed for closed economies should a priori not fit very well when it comes to reproduce and forecast its business cycle. Interestingly, in turned out that this first presumption is not quite true. A further conjecture is, that a two-country DSGE model approach (Austria and Euro area) should be better suitable to reproduce Austria's business cycle because Austria – as a member of EU and the Euro area – is economically heavily integrated into the Euro area. Therefore, shocks in the Euro area determine heavily Austria's business cycle.

Turning point of the Austrian business cycle in 2008:

Before evaluating the predictive power of the DSGE models let's have a look on their ability to catch the turning point of the business cycle in 2008. The pre-crisis peak of the Austrian business cycle was reached in 1Q2008. After that real GDP began to decline until the trough was reached in 2Q2009. Whereas all eight DSGE models got the turning point correctly after the information of the default of Lehman Brothers, only five models realized the break of the business cycle in their pre-Lehman Brothers estimations (see Table 2). In 1Q2008 the models of An and Schorfheide, Smets and Wouters, Poutineau and Vermandel, Almeida and Breuss and Rabitsch got the turn already right. The models of Lubik and Schorfheide, Del Negro and Schorfheide and the NAMW did not realize the turning point early in 2008 (see also the Figures 1 and 2).

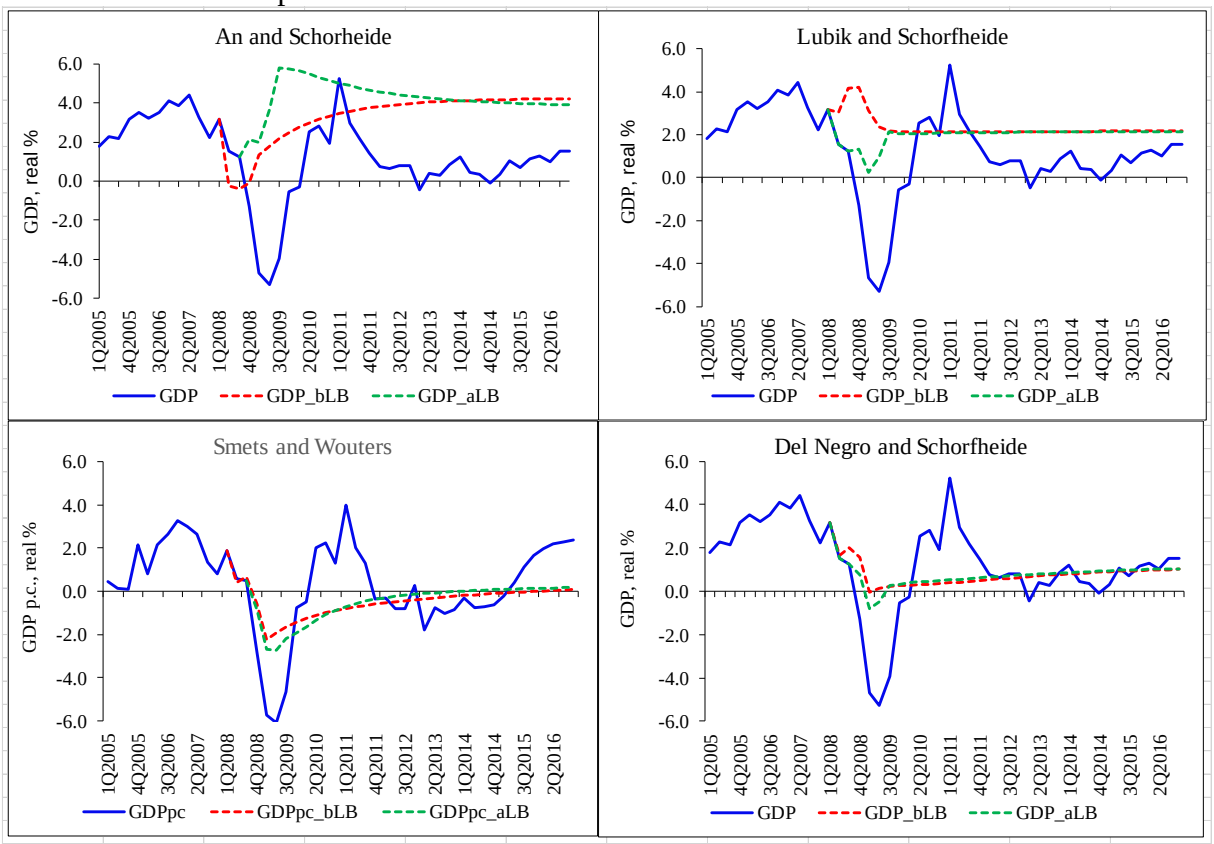
Ex-ante forecasting the Great Recession in 2009:

Before Lehman Brothers (1Q2008): At the beginning of 2008 (before the default of Lehman Brothers) one could already have known the burst of the subprime sector in the USA evolving already in 2007[20]. At that point in time only a few DSGE models could realize that the Austrian business cycle passed the peak and began to turn into a recession. At the beginning

[20] After it reached the peak in 2006, since early 2007 the Case-Shiller Home Price Index began to decline dramatically.

of 2008, the closed economy models of Smets and Wouters and that of Del Negro and Schorfheide (see Figure 1) as well as the open economy model of Almeida and the two-country models of Poutineau and Vermandel als well as those of Breuss and Rabitsch realized that a recession is under way (see Figure 2).

Figure 1: Post-mortem of DSGE model forecasts of the Great Recession in Austria
Out-of-sample forecast of real GDP with small and medium-sized models



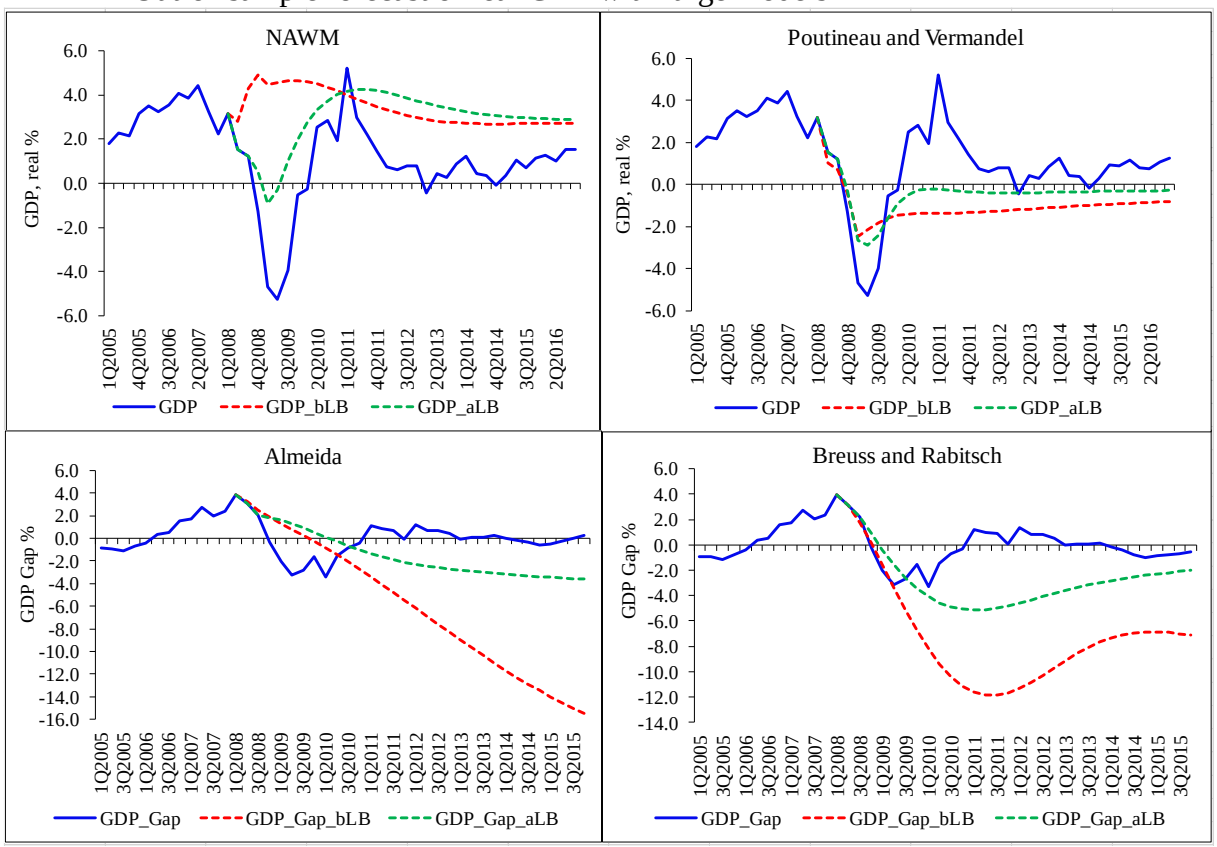
Except for the Smets and Wouters model (which uses real GDP per capita), all models measure the business cycle in real GDP (annualized) growth rates in %. GDP_b(a)LB = is GDP estimated before (after) the default of Lehman Brothers.

Measured by NRMSE, Poutineau and Vermandel (the two-region Euro area model with banking) wins the trophy with the best score (see Table 2). The second-best performer in ex-ante forecasting the recession was the SW model. Although catching the turning point early in 2008 the largest errors over the whole recession period 2008-2010 exhibited the two-country model of Breuss and Rabitsch. Quite bad was the NAWM model in realizing the turning point and catching the recession at the beginning of 2008.

After Lehman Brothers (3Q2008): During 2008 the financial crisis broadened and reached its climax with the default of Lehman Brothers on 15 September 2008. After that unique event

the inter-bank market crashed, a credit squeeze stopped new real investments, the financial crisis turned into a real recession, called the Great Recession. By hindsight we understand the mechanics of the emergence of the Great Recession in 2009. At the end of 2008, after Lehman Brothers only few forecasters realized the consequences of the causes of the crisis and were therefore not able to forecast properly the recession.

Figure 2: Post-mortem of DSGE model forecasts of the Great Recession in Austria
Out-of-sample forecast of real GDP with large models



The NAWM and the Poutineau and Vermandel model measure the business cycle in real GDP (annualized) growth rates in %. The Almeida and Breuss and Rabitsch model use the GDP gap in % of real GDP. GDP(GDP_Gap)_b(a)LB = the estimated GDP (GDP Gap) before (after) the default of Lehman Brothers.

Nevertheless, all eight DSGE models were able to detect the turning point of the Austrian business cycle after Lehman Brothers (see Table 2 and Figures 1 and 2). Again, the best performer with the least forecasting errors was the two-country DSGE model with banking of Poutineau and Vermandel. Closely at the second place comes the SW model. The worst performer at the end of 2008 was the simplest model of An and Schorfheide.

Ex-ante forecasting the Great Recession in 2009 and the recovery thereafter:

Measured by the normalized RMSE before and after Lehman Brothers, the best performer over the period 2008-2016 was the small-scale SW DSGE model with financial frictions by Del Negro and Schorfheide. However, also the SM model and those of Poutineau and Vermandel performed quite well. The worst score (highest NRMSE) produced the DSGE model of Almeida (see Table 2 and Figures 1 and 2).

Inflation

Making the same forecasting exercise for nominal variables, more precisely for the ex-ante forecast of the performance of inflation during the Great Recession produces the following results:

- The best inflation performance (the lowest NRMSE figures) exhibits the Pouteneau and Vermandel model during the Great Recession 2008-2010; the best inflation performer in the post-recession period (2010-2016) was the Almeida model. The worst performance delivered the NAWM model.
- Comparing the predictive power of real GDP with those for inflation the results were as follows:
  - During the Great Recession 2009 the models of Del Negro and Schorfheide and that of NAWM forecasted GDP better than inflation before and after Lehman Brothers. Poutineau and Vermandel as well as Breuss and Rabitsch forecasted inflation better than GDP after Lehman Brothers. The small (An and Schorfheide, Lubik and Schorfheide) and medium-sized DSGE models (Smets and Wouters) were better in forecasting ex-ante the inflation than real GDP.
  - In the post-recession period 2009-2016 five out of the eight DSGE models forecasted ex-ante real GDP better than inflation. Only the models An and Schorfheide, Almeida, as well as Breuss and Rabitsch forecasted inflation better than real GDP.

4. How Performed Non-DSGE Methods?

The primary goal of this paper was to test the ex-ante forecasting quality of DSGE models in case of a severe recession. For purposes of comparison, we take two Non-DSGE methods to evaluate post-mortem the Austrian Great Recession. One is a global macro model of Oxford Economics, the other is the expert forecasting of WIFO.

4.1 OEF Global Economic Model

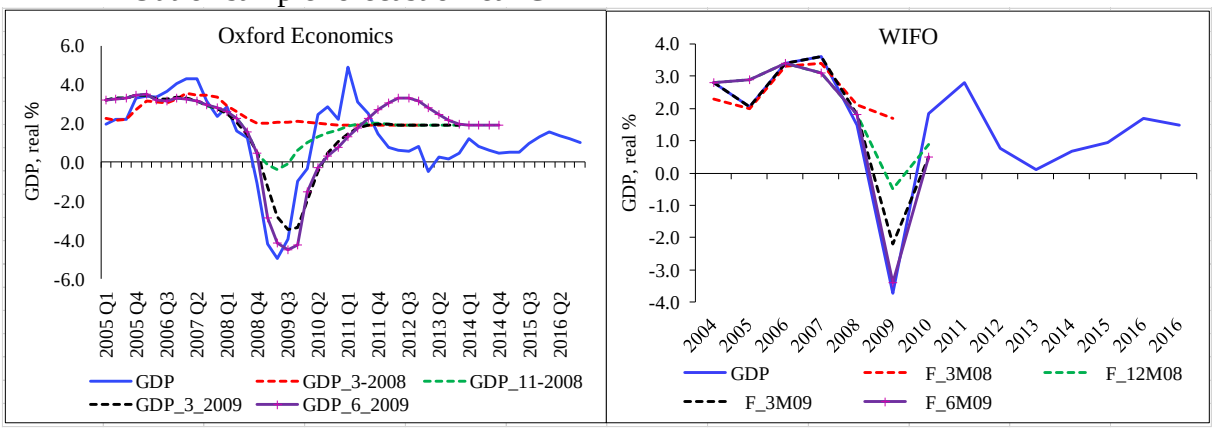
Oxford Economics[21] forecasts monthly the economic development of 80 countries in its Global Economic (Macro) Model.

We evaluate the forecast of Austrian real GDP growth executed at two different junctures of the crisis:

(i) *Before the default of Lehman Brothers (bLB)*. We take the OEF database as of 3M2008 and forecast the further development of the Austrian GDP in the coming years up to the end of 2012.

(ii) *After the default of Lehman Brothers (aLB).* Here we take the OEF database as of 11M2008 and execute with it a forecast of the following years up to the end of 2013.

Figure 3: Post-mortem of Non-DSGE model forecasts of the Great Recession in Austria
Out-of-sample forecast of real GDP



GDP = realized real GDP growth in %; F_3M08 = Forecast in March 2008 etc.
The Oxford Economics model uses real GDP (quarterly) growth rates in %; the WIFO forecast is based on annual real GDP growth rates in %

As one can see from Figure 3, at the beginning of 2008 the OEF model did not realize that a recession is advancing. Only after Lehman Brothers the growth rate of real GDP was forecasted slightly negative (-0.2%) for the year 2009. Then the Oxford Economics forecaster gradually approached the Great Recession in 2009. Nevertheless, measured by NRMSE, the ex-ante forecasting performance of the OEF Global model was not the worst in comparison with DSGE models (see Table 2).

4.2 WIFO's Expert Forecasts

The Austrian Institute of Economic Research (WIF0) makes quarterly forecasts (or revisions of previous forecasts), however, it does not forecast quarterly variables but only yearly macro

[21] See the website: http://www.oxfordeconomics.com/

variables, like real GDP. WIFO always forecasts only one year in advance. The forecast is done by a team of experts. Only afterwards the forecast is translated into the WIFO macro model for policy simulation purposes.

Before Lehman Brothers, in March 2008 WIFO already anticipated a turning of the business cycle due to gloomy news about the development (subprime and banking crises) in the USA. After Lehman Brothers in December 2008, WIFO already forecasted a slight decline of real GDP for 2009 (-0.5%). Then the GDP growth was corrected downwards step by step: March 2009 (-2.2%). In June 2009 (-3.4%), WIFO forecasted more or less correctly the final decline of real GDP (-3.7%) in the year 2009 (see Figure 3).

5. Conclusions

DSGE (Dynamic stochastic general equilibrium) models are the common workhorse of modern macroeconomic theory. They are widely applied in academic research but also in international institutions (IMF, European Commission, ECB), in particular in central banks. DSGE models serve three purposes: They are used to predict (forecast) and explain (story-telling) co-movements of aggregate time series over the business cycle (real business cycle theory) and to perform policy analysis (policy experiments: IRF implications of shocks of fiscal and monetary policy and of technical change). Whereas the two latter applications were in the forefront of applications since its inception, the forecasting perspective is only recently topical.

Most forecasting evaluations with DSGE models so far were executed for the US economy and for the Euro area (at the ECB). In this study, we performed a post-mortem of DSGE model forecasts of the Great Recession (2009) in Austria. For this purpose, eight DSGE models with different characteristics (closed and open economy models; one and two-country models) were used.

Other than expected DSGE models are quite suitable in detecting ex-ante turning points of severe recessions. The forecasts of real GDP growth for Austria are obtained at two different junctures of the crisis that led to the recession: At the beginning of 2008 and at the end of this year (after the default of Lehman Brothers). Whereas early in 2008 only five of eight models detected the turn into recession, after Lehman Brothers all eight DSGE models correctly saw the Austrian business cycle turning into recession. With respect to the predictive power measured by RMSE values those models which already included factors which led to the Great Recession, namely financial frictions and inter-bank features performed the best. Surprisingly, the most cited Smets and Wouters model, a closed economy DSGE model also

performed for Austria – a prototype open economy – quite well in ex-ante forecasting the crisis.

In comparison, non-DSGE methods like the ex-ante forecast with the Global Macro Model of Oxford economics and the WIO's expert forecasts performed not better than DSGE models in the crisis.

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Annex: Ex-post (within-sample) DSGE model forecasts of Austria's GDP

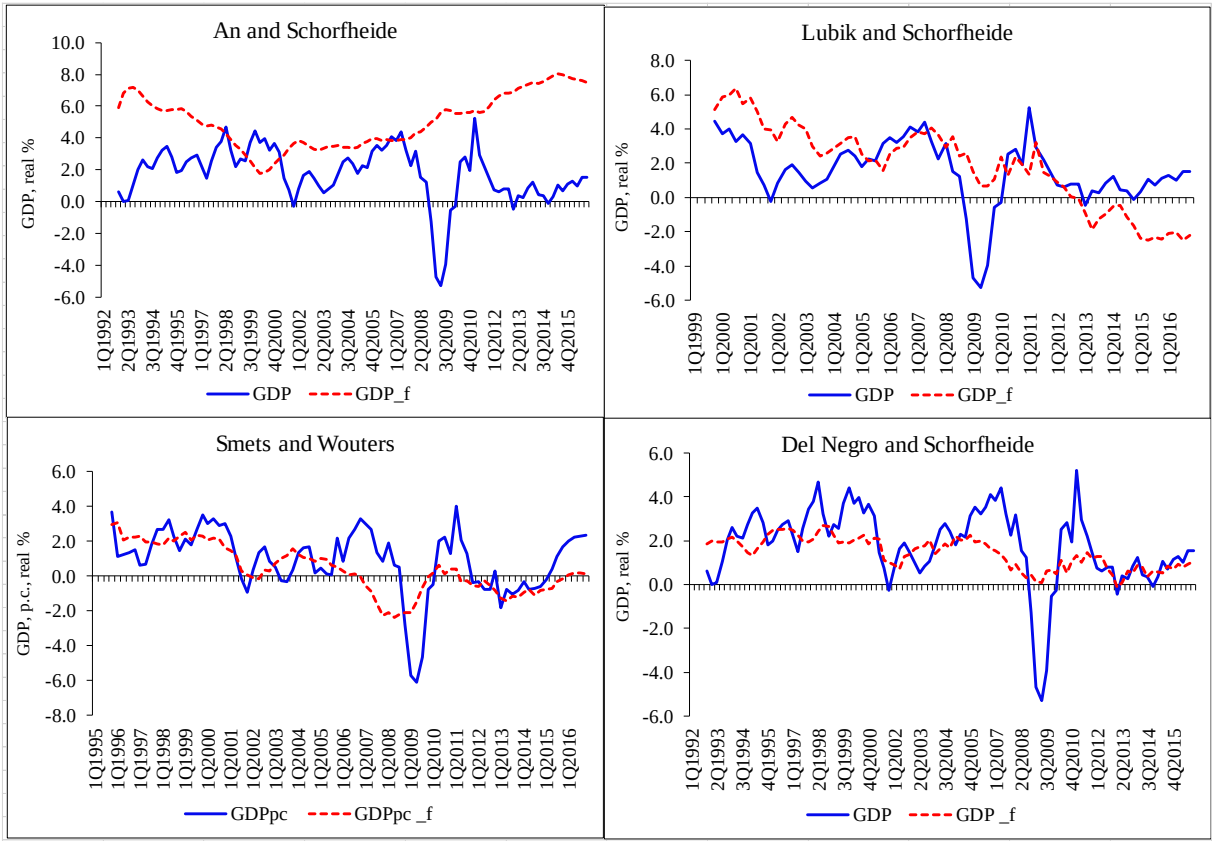
Small and medium-sized DSGE models

1-Step ahead mean forecasts, executed with YADA: With the exception of the Smets and Wouters model (which uses real GDP per capita), all models measure the business cycle in real GDP (annualized) growth rates in %. GDP = realized GDP; GDP_f = ex-post forecast of GDP.

Large DSGE models

1-Step ahead mean forecasts executed with YADA (NAWM) and Dynare (the 3 other models): The DSGE models of Almeida and Breuss-Rabitsch use the GDP Gap in %.

Small and medium-sized DSGE models



Large DSGE models