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SOME NOTES ON PROBLEMATIC ISSUES IN DSGE MODELS[1]

ABSTRACT: *We review some of the problematic issues in DSGE models, which are currently much discussed in the economics profession. All of these issues are concerned with the DSGE models' (in)ability to match aspects of macroeconomic variables' observed behaviour. The optimizing agents framework implies that Ricardian equivalence typically holds, which is clearly at odds with the empirical evidence. A distinguishing feature of DSGE models is the assumption that structural parameters are invariant to policy changes. We argue that not all of them can be considered independent from economic policy. It is typical for DSGE models that agents form rational expectations, which can be considered unrealistic. The typical procedure for estimating a DSGE model is to use revised data. As some empirical studies suggest, a model's behaviour may be different if real-time data are considered. It is also usually assumed that the monetary authority uses the interest rate as a tool of monetary policy. Nowadays, nominal interest rates are close to zero in many economies and cannot be lowered further.*

KEY WORDS: *DSGE model, fiscal policy, structural parameters, rational expectations, learning algorithm, real-time data, zero lower bound*

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1. MOTIVATION

Dynamic Stochastic General Equilibrium (DSGE) models are dynamic macroeconomic models of an economy's business cycle behaviour. Their distinctive feature is that they are derived from microeconomic foundations.[2] The New Keynesian branch of DSGE models is nowadays considered as a benchmark for monetary policy analysis and forecasting and these models are widely used by central banks all over the world for these purposes.[3] It seems natural that DSGE models, nowadays considered part of mainstream economic theory relating to business cycle fluctuations, have been subject to many criticisms. J. Faust has been a key contributor to this debate.[4] While acknowledging that DSGE models are a helpful tool in monetary policy analysis and that their development represents a great academic achievement, Faust calls for a systematic approach to establishing the best methods and practices for using these models. This systematic approach should take into account the fact that DSGE models provide a far from perfect description of the real world. In spite of the steady progress in DSGE modelling, important factors are always potentially omitted, and even the most complex DSGE models still offer a rather coarse approximation of reality. We should not take the results obtained from DSGE models as the unambiguous truth; instead, we should put the results obtained to several tests capable of raising our confidence in them.

This paper contributes to the debate on the weaknesses of DSGE models by reviewing some of the practical, rather than theoretical, problematic issues in DSGE modelling, which have recently been the subject of discussions in the economics profession. All of these are related to DSGE models' inability to match certain aspects of macroeconomic variables' observed behaviour. A discussion of these difficulties helps us understand the models' capabilities and limitations, and may thus contribute to a more responsible use of DSGE models for monetary policy analysis and forecasting in central banks and other institutions. In this sense, this paper's aim is similar to that of Brázdik, Hlaváček, and Maršál (2012), who discuss the issue of financial frictions in DSGE models.

In our paper we discuss five problematic issues associated with DSGE models. First, we devote the next section to fiscal policy and its effects. We discuss a discrepancy

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2 For a detailed exposition of DSGE models see Galí (2008), Woodford (2003) or Walsh (2010).

3 For an example of central bank policy models see Smets and Wouters (2003) where the ECB's policy model is presented, or Adolfson et al. (2007) where the Swedish Central Bank's "RAMSES" model is presented.

4 See Faust (2008, 2009a, 2009b, 2012).

between the effects of fiscal policy in DSGE models and empirical evidence on the effects of fiscal shocks. We also present various approaches designed to reduce this discrepancy. Section 3 is concerned with the issue of structural parameters. We argue that not all of these can be considered independent from economic policy, and explain why. In addition, we discuss some empirical evidence on drifting in parameters and the issue of modelling time-varying parameters in DSGE models. Section 4 is devoted to the role of rational expectations in DSGE models. We show the main pitfall of such expectations and discuss alternatives in the form of learning algorithms. Section 5 reviews the consequences of the use of real-time versus revised data in DSGE modelling. Section 6 deals with the non-linearity problem represented by the zero lower bound on the interest rate, in terms of both the economic consequences of this constraint and the possible solution methods. The final section concludes.

2. EFFECTS OF FISCAL POLICY

DSGE models are based on optimizing agents, which maximize their objective functions subject to their respective constraints. However, if we want to examine effects of fiscal policy, a theoretical framework based solely on optimizing agents is insufficient. If we incorporate the governmental sector into the otherwise standard DSGE model, no matter whether we choose the RBC (Real Business Cycle) or NK (New Keynesian) model, the results concerning effects of fiscal policy are rather strange; see Baxter and King (1993). The optimizing agents framework implies that Ricardian equivalence holds in these models. Therefore, these models imply that an increase in government expenditure inevitably lowers, i.e., crowds out, household consumption. This model implication is clearly at odds with empirical evidence on the effects of fiscal shocks, as presented, e.g., in Fatás and Mihov (2002) and Perotti (2004). Empirical evidence on the effects of fiscal shocks suggests that private consumption tends to rise following an increase in government expenditure. Usually, this is referred to as a crowding-in effect.

An elegant solution to this problem lies in the concept of non-Ricardian households, and in partially abandoning the optimizing agent framework. Mankiw (2000) introduces non-Ricardian households and argues that neither the concept of infinitely lived households nor the concept of overlapping generations can provide a solid basis for analysing the effects of fiscal policy. Using stylized facts about households, he argues that there are at least two types of household in modern economies: i) low-wealth households that fail to smooth their consumption over time and ii) high-wealth households that smooth their consumption not only from year to year but also from generation to generation. While the behaviour of the latter group of households can easily be described by the infinitely lived optimizing agents framework, the behaviour of the former group of households must be modelled using a rule-of-thumb.

In DSGE models with non-Ricardian households there are two types of household[5]: i) optimizing Ricardian households with free access to financial markets and ii) non-Ricardian households with rule-of-thumb behaviour such that they consume their entire earnings in every period.[6] The presence of non-Ricardian households in the model ensures the crowding-in effect of private consumption. According to Muscatelli et al. (2004a, 2004b), the share of non-Ricardian households in the overall population is about 50% in the euro area and 37% in the U.S. economy. The share of non-Ricardian households in total employment is even higher: 61% in the euro area and 59% in the U.S. economy. The main pitfall of this approach, as Galí, López-Salido and Vallés (2007) point out, is the results' high dependence on parameter values. They show that, for certain combinations of values of Calvo parameters and shares of non-Ricardian households, the model has no solution.

Linnemann and Schabert (2004) propose another means of obtaining the crowding-in effect of private consumption. They assume that public and private consumption are imperfect substitutes combined in a CES (constant elasticity of substitution) aggregate, which directly enters the utility function of households. They show that a positive shock in government expenditures raises private consumption if the elasticity of substitution between public and private consumption is sufficiently low. Ganelli and Tervala (2009) take a similar approach, and also add public consumption into the utility function of households. The main difference here is the assumption that public and private consumption are complements, which ensures that an increase in public consumption raises the marginal utility of private consumption.

Linnemann and Schabert (2006) take a different approach, based on the assumption that government expenditure is productive. They show that if government expenditures contribute to aggregate production, an increase in government expenditures leads to an increase in private consumption, even if the impact of government expenditures on production is small.

5 For an example of this model see Coenen and Straub (2005).

6 This type of household is often referred to as a hand-to-mouth household.

Ganelli (2007) shows that we can obtain a positive private consumption response after an increase in government expenditures by combining monopolistic competition, sticky prices, and an overlapping generation framework.

Ravn et al. (2006) propose a model with deep habit formation. Contrary to standard habit formation where households form habits over a composite consumption good, in a model with deep habit formation households form habits over individual varieties of goods. The presence of a deep habit in the model leads to countercyclical mark-ups and provides a mechanism for consumption to rise in response to a government spending shock.

3. HOW STRUCTURAL ARE STRUCTURAL PARAMETERS?

One of the reasons for the development of DSGE models was the need to derive a model that would be immune to the Lucas critique (Lucas 1976), i.e., a model whose parameters could be considered independent of economic (monetary) policy. The assumption that the parameters in DSGE models are more or less independent of monetary policy is crucial to the view that micro-founded DSGE models are a superior tool for monetary policy analysis. This assumption seems plausible for most parameters used in DSGE models; however, it is questionable for a few parameters: we can intuitively deduce that the values of some parameters used in the models may depend on the state of the economy or on the economic policy applied.

Structural changes, or changes in (structural) parameters, should be of particular interest to researchers who use DSGE models for policy analysis or prediction, since ignoring structural changes may lead to inaccurate forecasts and misleading policy recommendations.

3.1.Theoretical justifications

The Calvo parameters (see Calvo 1983), which usually govern price and wage stickiness in New Keynesian DSGE models, are a typical example. These parameters significantly influence the model dynamics, namely inflation responses and their sluggishness. The Calvo parameters can also be significantly influenced by inflation. The Calvo parameter denotes the portion of agents that are not able to reoptimize their prices in a given period and so leave them unchanged. It seems obvious that higher inflation would reduce this portion of non-optimizing agents, and vice versa. Fernández-Villaverde and Rubio-

Ramírez (2008) also explain this, and show that movements in time-varying Calvo parameters are negatively correlated with inflation.

The elasticity of labour supply, which is obviously influenced by the institutional arrangements of the labour market and by unemployment policy, is another example. Therefore, it is clear that we cannot claim that all DSGE model parameters are policy-invariant.

DSGE models with Calvo pricing have problems replicating some second moments found in the data. Specifically, these models give much higher results for volatility and much lower results for autocorrelation of inflation than those found in the data. In other words, these models cannot explain the observed persistence of inflation. In an attempt to solve this discrepancy, economists have proposed a number of extensions to the model in the form of additional frictions, such as habit formation in consumption, indexation to lagged inflation in price setting, rule-of-thumb behaviour, or various adjustment costs. Most of these additional frictions and parameters do not have clear economic reasoning and their integration into the model has been rather pragmatic. We cannot say with certainty that these models are fully immune to the Lucas critique.

3.2. Empirical findings

Researchers investigating changes in (structural) parameters have difficulty identifying them because, as Lubik and Surico (2010) point out, formal break tests have not yet been fully established for DSGE models estimated using Bayesian methods. Two different approaches are used to estimate structural changes in the DSGE literature: either a split-sample approach (or its variants), or a full-fledged parameter drift.

Canova (2006 and 2009) uses a small-scale New Keynesian DSGE model for a "rolling analysis" or "recursive analysis", which builds on a Bayesian estimation carried out many times for different time frames. Canova finds that private sector parameters change considerably, whereas changes in policy parameters are insignificant.

Fernández-Villaverde and Rubio-Ramírez (2008) estimate fully fledged drifting parameters, albeit only a couple at a time. This parameter drift is rationally expected by economic agents. A drawback of the methodology is that it does not explain the reason for the parameter change, and this drawback is further deepened by the computational cost of the procedure, which prevents a greater number of drifting parameters from being estimated simultaneously. The authors find great variation in the estimates of several parameters, some of which (e.g., Calvo parameters modelling nominal rigidities) they consider alarming.

In a comment to the aforementioned article by Fernández-Villaverde and Rubio-Ramírez, Schorfheide (2008) shows through a subsample analysis that statistically different parameter estimates produce almost the same impulse response functions, which raises the question of how to interpret changes in structural parameters. In another comment, Cogley (2008) stresses that the one-at-a-time approach used in the paper to model the parameter drift is inappropriate. More specifically, policy and Calvo parameters should drift together.

Fernández-Villaverde et al. (2010) present a medium-scale DSGE model with stochastic volatility and time-varying parameters in monetary policy rule. Consequently, they estimate the model using non-linear Bayesian methods on U.S. data. They find evidence that the parameters in the Taylor rule do drift, even after controlling for stochastic volatility.

For the Czech economy, Tonner et al. (2011) investigate the possible time-varying structure of DSGE models. They follow Andrle et al. (2009), who argue that models designed for monetary policy analysis and forecasting in an economy that is undergoing structural changes must include exogenous processes (technologies) capturing the specific characteristics of individual sectors. Tonner et al. (2011) conclude that the presence of structural changes and the convergence process in the data imply that the structural parameters in the model without technologies drift. Incorporating technologies causes the structural parameters to be relatively stable. From the perspective of monetary policy analysis and forecasting it seems more convenient to use sectoral technologies, owing to their aggregate form, and to assume that the structural parameters are stable.

Čapek (2016) identifies structural changes in the Czech economy in the period from 1996 to 2012 using a DSGE model estimated using Bayesian methods. A structural change is understood in this study as a statistically significant change in model parameter(s). Prior to the first quarter of 1999 there was a structural change that can be primarily attributed to shocks that only impacted the domestic economy, and to the domestic monetary authority›s increased preference for the stability of inflation and exchange rate growth. The elasticity of substitution between domestic and imported consumption goods also increased sharply in this period. As far as the recent economic recession is concerned, this was caused by a much more persistent worldwide technology shock. Habit formation dropped abruptly during the crisis, as households tended not to smooth their consumption much anymore. Recursive impulse response analysis on the model suggests that the propagation mechanisms in the model economy changed, implying that the identified structural changes were accompanied by a change in the model economy's behaviour.

4. RATIONAL EXPECTATIONS HYPOTHESIS

Although this cannot be regarded as a distinctive feature of DSGE models, most DSGE models employ a rational expectation hypothesis. The main reason for this is probably technical, since using rational expectations produces an elegant approximation of the model.

The rational expectations hypothesis implies that agents in a given economy have perfect knowledge of all the economy's parameters and their true values. If the parameters are estimated using Bayesian techniques, the rational expectations hypothesis implies that people know the exact probability distribution of all the parameters. In other words, the rational expectations hypothesis imposes some kind of superpower on the agents as regards gathering information and forming expectations. It is usually argued that on average people do not make systematic mistakes regarding their expectations, which may suggest that in aggregate the rational expectations hypothesis can provide a useful approximation of reality. However, this argument is not fully convincing, and so some economists have attempted to examine how the behaviour of the model would change if different kinds of expectation were assumed. Usually, these take the form of some learning algorithms, e.g., Bayesian or adaptive learning algorithms.[7]

Milani (2007) estimates several variants of a small-scale DSGE model that differ in their assumptions about expectation formation. Specifically, he compares models estimated under rational expectations and models estimated under a constant-gain learning algorithm. He finds that the models with the learning algorithm always outperform the models with rational expectations. He shows that the learning mechanism is able to generate endogenous persistence in the economy and improve the model's fit. Moreover, for a plausible model fit with the learning mechanism, no additional mechanical sources of persistence such as habit formation in consumption or indexation to lagged inflation are required.

7 A good introduction to the theory of learning algorithms can be found in Evans and Honkapohja (2001).

These additional frictions, as I argued in the previous section, do not have any clear economic reasoning and their integration into the model was pragmatic.

Slobodyan and Wouters (2012) proceed in a similar way, but use a more complex model from Smets and Wouters (2007). They also find that the model with the learning algorithm outperforms the model with rational expectations; however, the resulting differences are not so pronounced as in Milani (2007), which implies that in more complex models, rational expectations might be a plausible approximation of the reality. This might seem counterintuitive, as in a more complex environment it is less likely that economic agents know all the relevant distribution functions of random variables. The reason is probably that more complex models make use of plenty of nominal and real frictions, which generate the persistence observed in the macroeconomic data. Learning algorithms can be seen as a substitute for these frictions in generating persistence of macroeconomic variables. Thus, in more complex models there is no urgent need for incorporating learning algorithms, as these models are rich enough to mimic persistence in the data.

5. DEALING WITH REVISED OR REAL-TIME DATA

The typical procedure for using data in DSGE models is to download ready-to-use time series from databases like Eurostat or OECD, compute the required data transformations, and use these as observable variables. This procedure has potential drawbacks if the data used are subject to revision, which is typically the case for frequently used series like GDP or inflation. Time series of data that are subject to revision mix together revised and unrevised data: the latest observation is typically a first (or even flash) estimate of the current value, while observations that are several years old have often already undergone many revisions.

Theoretically, most DSGE model parameters are more precisely estimated with revised data, although policy parameters, for example, are more precisely estimated using the real-time data that were available to the policymaker at the time of decision-making. Policy parameters reflect the policymaker's reaction to data that are observed in real time. Using revised data for the historical analysis of policy parameters may result in misleading conclusions (see, e.g., Orphanides 2001). On the other hand, autoregressive parameters and arguably also non-policy parameters are more precisely estimated using revised data.

The unreliability of real-time macroeconomic data is a well-known issue, and many studies have investigated the properties of data revision. Orphanides and van Norden (2002) report that the main issue is not the revision of published U.S. data, but the unreliability of end-of-sample trend estimates. On the other hand, Cusinato et al. (2013) show that data revision and the end-of-sample problem both contribute to uncertainty about the Brazilian output gap, but do not find any evidence that the former is less important than the latter. Investigating the empirical properties of U.S. macroeconomic data, Aruoba (2008) finds that revisions to the data are biased and predictable. Rusnák (2013) reports that revisions of Czech GDP data and its components are substantial. He studies whether these revisions are "news" or "noise", i.e. whether the revisions are predictable or unpredictable, and ascertains in-sample predictability and out-of-sample unpredictability for most variables of interest.

A great deal of research effort has focused on exploring the analytic consequences of using real-time data in analysis. One stream of literature concentrates on monetary policy. For example, Orphanides (2001) uses a Taylor-type rule as an example of different policy recommendations based on real-time vs. final data, and argues that a monetary policy reaction function estimated on final data provides a misleading description of historical policy. Similar conclusions, i.e., that real-time data play a (significant) role, were reached by, e.g., Horváth (2009) and Belke and Klose (2011). More recent literature also uses DSGE models with monetary rules as a tool for monetary policy investigation. Vázquez et al. (2010) and Casares and Vázquez (2012) establish that monetary policy parameters are robust to real-time specification. On the other hand, Neri and Ropele (2012) show that there is indeed a statistically significant difference in policy parameters when real-time data are considered.

Kolasa et al (2012) put a New-Keynesian DSGE model to the test in real-time forecasting with data from the Survey of Professional Forecasters (SPF). The paper concludes that if we support the model with SPF nowcasts, the model forecasts reasonably well. Clements and Galvão (2011) concentrate on business cycle analysis and establish that using older data vintages also improves output gap and inflation trend estimates in real time. Croushore and Stark (2003) show that using different data vintages may lead to (statistically significantly) different model parameter estimates. Interested readers may turn to Croushore (2011) for an extensive survey of real-time data literature.

Čapek (2014) investigates the differences between parameter estimates of monetary policy reaction functions using real-time data and those using revised data. The model is a New Keynesian DSGE model of the Czech, Hungarian, and Polish small open economies in interaction with the euro area. Unlike the related literature, this paper uses separate vintages of real-time data for all successive estimations. The paper reports several statistically significant differences between parameter estimates of monetary policy reaction functions based on real-time data and those based on revised data. The parameter whose estimate is the most affected by the use of real-time data is the preference for output growth. This result is common across the countries in the study. The results suggest that real-time data matter when conducting a historical analysis of monetary policy preferences.

Čapek (2015) investigates the differences between parameters estimated using real-time data and those estimated with revised data. The models used are New Keynesian DSGE models of the Czech, Polish, Hungarian, Swiss, and Swedish small, open economies in interaction with the euro area. The paper also offers an analysis of data revisions of GDP growth and inflation and trend revisions of interest rates. Data revisions are found to be unbiased and not autocorrelated in all countries. Inflation is usually measured more accurately in real time than GDP growth, but this is not the case in the euro area. The results of the core analysis suggest that there are significant differences between parameter estimates using real-time data and those using revised data. The model parameters that reveal the most significant differences between real-time and revised estimations are habit in consumption and persistence of domestic supply, of demand and of world-wide technology shocks. Typically, the differences between the estimations follow the differences in the quality of information contained in the data. Revised data are less noisy and more accurate. If the difference in the data quality is big enough, the optimal behaviour of economic agents (which is based on the data) differs and the trajectories of DSGE model parameters differ as well. The impulse response analysis suggests that the model behaves differently when based on real-time data compared to its behaviour with revised data.

6. ZERO LOWER BOUND ON INTEREST RATE

The recent economic situation in the U.S. has been similar to that in Europe: the economy is in recession or slowly recovering from it, inflation is falling, and nominal interest rates are close to zero and cannot be further lowered to boost the economy. This situation is described as the liquidity trap or zero lower bound (ZLB) on the interest rate, which set limits on monetary policy's influence on the economy. The recent situation has naturally increased interest in models with the zero lower bound, which can explain the consequences of this policy for macroeconomic policy and the economies in question. The zero lower bound on interest rate represents an occasionally binding constraint that brings nonlinearities into the models. That nonlinearity complicates quantitative analysis and limits the application of classical linearization techniques and toolboxes. A huge number of papers investigate the zero lower bound on interest rates. Here, we first focus on methods of solution[8], and then on selected economic problems addressed in these papers.

One group of papers uses fully nonlinear solution techniques to analyse small New Keynesian models. These global methods have several advantages. The solution is accurate and there are no errors connected with (log) linearization. Furthermore, these methods can capture precautionary motives, i.e., when agents' behaviour is influenced by uncertainty about future states of the economy. The disadvantage of these methods is the well-known curse of dimensionality, which restricts their use to medium-scale models. However, this drawback can be partly eliminated using some advanced projection methods that are computationally more efficient. Fernández-Villaverde et al. (2012) use a calibrated New Keynesian model which they solve by a projection method, Smolyak's algorithm; Gust, López-Salido, and Smith (2012) solve a stochastic nonlinear model by a projection method and then estimate it using Bayesian techniques. Aruoba et al. (2014) also use a global projection method with Chebyshev polynomials to find decision rules, and a particle filter for model estimation. All these models are quite small, comprising just a few equations.

A further generation of papers uses non-linear perfect foresight solvers. Braun and Korber (2011) use an extended path solution method established by Adjemian and Juillard (2011). The nonlinear equations are solved forward for a sufficiently large number of periods (e.g., 100), after which the economy returns to a steady state. Time is then moved forward and this procedure is repeated sequentially for a new set of shocks and new initial-state variables. This is done for the whole observed period. Although this approach solves nonlinear equations, it cannot deal with precautionary motives connected to expectations of future shocks. The other disadvantage is that the algorithm is quite costly in computational terms: it can only be used for models with a limited number of state variables, and tends to be slow and unstable.

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8 For a good exposition and comparison of methods for solving DSGE models, see Aruoba et al. (2006).

A third group of papers uses log-linearized versions of the model, with the exception of the zero lower constraint, which is used in exact form. Eggertsson and Woodford (2003) solve the model using a piecewise linear approximation method. The dynamics of the model are driven by a two-state Markov chain with absorbing state for the discount factor. The high discount factor takes the economy to the ZLB and in every period there is a probability that the discount factor will move to its long-run value where the zero nominal interest rate is never attained again. A similar method is used by Christiano, Eichenbaum, and Rebelo (2011) in their model without capital. A more general version of this algorithm was implemented for the Dynare toolbox[9] by Guerrieri and Iacoviello (2015). Occasionally binding constraints (including ZLB) can be considered as different regimes of the same model. Under one regime the constraint is binding; under the other regime the constraint is slack. The piecewise linear solution evaluated around the same point but in different regimes can produce high nonlinearity. The advantage of this method is that it can be applicable to models with a large number of state variables: it is implemented in Dynare, which is a very popular and convenient toolbox, and its computational burden is small and the solution quite fast. It also has some limitations, however. The algorithm is not able to capture precautionary behaviour connected with the possibility that the constraint will bind in the future because of as yet unrealized shocks. Furthermore, the algorithm relies on a linear approximation that may lead to misleading conclusions. Braun et al. (2012) document this fact in a comparison of nonlinear and log-linearized solutions of the model with a fiscal multiplier in a liquidity trap environment.

A compromise between accuracy of solution and tractability and speed of solution is found in studies by Erceg and Lindé (2010) and Holden and Paetz (2012). Their method is based on adding a series of shocks (innovations) to the interest rate variable so that the zero bound constraint is satisfied. These innovations are assumed to be correctly anticipated by the agents. The advantage of this algorithm is that it is quite simple, fast, and easy to implement using Dynare routines. It can also be used in models with many state variables and for any number of constrained variables. Finally, this algorithm enables precautionary motives to be captured, which is an improvement on previous piecewise linear methods or perfect foresight solvers.

The papers that deal with the ZLB mainly focus on its empirical analysis and/or implications for monetary or fiscal policy. On the latter, many papers explore the

9 Dynare is a toolbox for solving and estimating DSGE models (Adjemian et. al. 2011).

size of the fiscal multiplier. They mostly find that the fiscal multiplier is larger when the economy is at the ZLB, but Erceg and Lindé (2010) argue that this is true only for small-scale spending programmes. Fernández-Villaverde et al. (2012) find that the fiscal multiplier is around three times larger at the ZLB and the marginal multiplier is much larger than average. Christiano, Eichenbaum, and Rebelo (2011) find that the increase to the fiscal multiplier is not so substantial when the model economy includes capital. Aruoba et al. (2014) estimate a New Keynesian model on data from the USA and Japan. They show that the size of the fiscal multiplier depends on the regime where the economy is. In a deflationary regime (as experienced by Japan) the ZLB has no effect on the size of the multiplier, while in a targeted-inflation regime (as experienced in the US) the multiplier is doubled.

Eggertsson and Woodford (2003) show that credible monetary policy commitment to price level targeting can reduce welfare distortions connected to the ZLB. Adam and Billi (2006) focus on optimal monetary policy at the ZLB. They find that this constraint on the interest rate does not produce large welfare losses, but that central banks should behave more aggressively when facing adverse shocks. Jung et al. (2005) argue that the optimal monetary policy path is characterized by inertia, i.e., central banks should keep the interest rate at zero level even if the natural interest rate returns to positive values.

Braun and Korber (2011) investigate the behaviour of a New Keynesian model calibrated to the Japanese economy. They find that this model exhibits quite orthodox behaviour in a low interest rate environment when the government multiplier is less than one. Coenen et al. (2004) show that the implications of the zero lower bound are negligible in reaction to common shocks experienced in the US during the 1980s and 1990s. However, these results depend nonlinearly on the size of the inflation target: for targets between zero and one the volatility of output increases significantly, and that of inflation to smaller extent. Gust, Lopez-Salido, and Smith (2012) focus on the empirical implications of the ZLB in the US economy. They look at which shocks took the US economy to the lower bound and how much this constraint contributed to the severity of the Great Recession. They find that the restriction on the interest rate contributed to a drop in GDP of around 20% and that in a hypothetical situation in which monetary policy is not constrained the GDP would be 1% higher on average. Ireland (2011) also argues that without a constraint on the interest rate the US economy would recover from the recession sooner and more quickly.

Few papers have dealt with the implications of the ZLB in the Czech economy. Franta et al. (2014) discuss alternative monetary policy tools, in particular exchange rate interventions, as a solution for the situation where the interest rate is constrained by the zero lower bound. Malovaná (2015) examines the effects of various shocks under different monetary policy regimes when the economy is at the ZLB. Her analysis is carried out on a DSGE model estimated on data from the Czech economy. She finds that when the economy is at the ZLB, the volatility of the real and nominal variables is amplified in reaction to domestic demand shock, foreign demand, and financial shocks and terms of trade shocks. When the central bank fixes the nominal exchange rate at the ZLB, it helps to mitigate deflationary pressures and to recover economic activity. Hloušek (2014) analyses a small open economy model estimated using Bayesian techniques on Czech data. The results of his simulations show that the most dangerous shocks that can take the economy to ZLB are domestic cost-push shock and foreign preference shock. The former shock is identified as the most volatile and thus has great potential to influence inflation and consequently bring the economy into the liquidity trap. The impact of the latter shock is important due to the high openness of the Czech economy. The ZLB also has implications for consumption and output behaviour, but these are quantitatively small. Hloušek (2016) also deals with the impact of the zero lower bound on the economy, but his research question is how the size of the inflation target set by the central bank influences the distortions caused by ZLB constraint. His results show that for an inflation target of 2% the costs are negligible, but that they increase steeply with lower target values. The largest impact is on the average values of output, consumption, and investment: inflation is only slightly influenced. The reasoning is that in monetary policy rules the central bank gives higher weight to inflation than to the output gap.

7. CONCLUSION

The topics discussed in this paper pertain to the difficulties that empirical DSGE models have in mimicking the data of a real economy.

In some cases these problems are connected to the models' mechanisms themselves. For example, it is typical for DSGE models to assume Ricardian equivalence, rational expectations, and that the monetary authority can use the interest rate as a tool of monetary policy. Nowadays, all of these model mechanisms are questionable. The data reveal that Ricardian equivalence does not hold in real economies. One possible solution may be to incorporate non-Ricardian households into the model. The unrealistic assumption of rational expectations can be overcome by learning algorithms, yet the quantitative gains of adding learning algorithms to complex models are negligible. As for policy problems, the zero lower bound on interest rates must be modelled explicitly in order to describe the specific situation that central banks find themselves in when they are unable to lower interest rates in practice. Modelling the zero lower bound is a difficult non-linear problem that requires further research to be fully understood.

In some other cases, the problem lies in the interpretation of the DSGE models' output. These difficulties may stem from model design or from common uses of DSGE models. Uncertainty about the (non)structural nature of model parameters readdresses the Lucas critique. Are parameters invariable when policy changes? In some cases, the answer to this is no, which calls for a redefinition of structural parameters and their role in DSGE models. The final issue we have surveyed is the inappropriate use of data. The typical practice when using DSGE models is to use as observable variables ready-to-use time series from databases like Eurostat or OECD; however, a number of empirical studies suggest that the models' behaviour may be quite different if real-time data are considered.

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