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# DSGE Models Used by Policymakers: A Survey

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# DSGE Models Used by Policymakers: A Survey[1]

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Abstract:

The paper conducts a comprehensive survey on the current state of the dynamic stochastic general equilibrium (DSGE) models developed by policy institutions, including central banks, government agencies, and international organizations around the world. Our main sample consists of 84 models developed by 58 institutions, and many of them were developed or updated after the 2008 financial crisis. We first document the evolution of macroeconomic models used for policy purpose, and then provide summary statistics on the models by type of institution, region, and number of authors of the publication. We find that there is a steady increase in the development of DSGE models by policy institutions. While central banks have been the main users of DSGE models, more government agencies in Europe have been actively developing their own DSGE models in the years following the 2008 Global Financial Crisis. We also find that some institutions have multiple DSGE models serving different purposes. Next, we narrow our focus to a subset of 42 models that are owned and actively used by policy institutions, and conduct a model comparison based on five key model features. Although the models share common basic structures, there are large variations in parameter values and modelling strategies, some of which do not necessarily reflect the findings of the empirical literature. Finally, we create a score card for each model depending on whether the model incorporated recent empirical findings on the five model features. Two models have a score of 4 out of 5, and the overall average is 2.21. In conclusion, there is a greater need for future DSGE policy models to adopt more recent findings in the empirical literature.

Keywords: DSGE model, financial friction, intertemporal elasticity of substitution, non-Ricardian household

[1] The analysis and conclusions are provided by the authors and do not reflect the views of the Ministry of Finance, Japan or members of its staff.

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## 1. Introduction

In recent years, a broad consensus has emerged among the academics that different types of macroeconomic models should be used for different purposes (Blanchard, 2018). In the field of macroeconomic *policymaking*, central banks, government agencies such as the Ministry of Finance, and international organizations have been the front runners in developing the dynamic stochastic general equilibrium (DSGE) models. The DSGE modelling practice has received many critiques from both researchers as well as practitioners following the Global Financial Crisis of 2008 and the Euro Crisis of 2010 because most of them did not have model structures that enable them to analyze the effect of the crises and subsequent policy responses. Since then many policy institutions have responded by applying modifications to their models, such as inclusion of unemployment, financial friction, and unconventional monetary policy, among others. Policy institutions have been increasingly using the DSGE model as one of their most important policy analysis tools to this day.

This paper's main objective is to summarize the current state of the DSGE models developed by policy institutions to obtain an updated perspective on "what is happening on the ground" in the years after the Global Financial Crisis of 2008. To this end, we first collected information on 84 DSGE models, three quarters of which were developed after the Global Financial Crisis. Second, we provided basic descriptive statistics, such as the type and geographical location of institutions involved, stated objectives of model development, number of models held by each institution, and the number of the authors involved. Third, we conducted model comparison using a subset of 42 models based on five household-related model features, including intertemporal elasticity of substitution for consumption, habit formation, household heterogeneity, financial friction, and labor supply elasticity. In our view, these five features

capture the main differences across existing DSGE models and crucially affect model performance that are related to monetary and fiscal policy.[3]

There are several key findings. First, while central banks are the main users of DSGE models in the context of policymaking, in the years following the 2008 Global Financial Crisis, more government agencies in Europe became involved in the development of this class of models. Second, two-fifths of the institutions in our sample have more than one DSGE model, each tailored to different objectives. Third, the number of the authors involved in the development of DSGE models has been rising, indicating that the models may have become more complex over time. Fourth, we find large variations in the parameterization of key parameters, which do not necessarily reflect the findings of the corresponding empirical literature. Some parameter choices appear to overstate the effectiveness of both monetary and fiscal policy. Finally, we create our own score card for each model based on whether the model has incorporated the recent empirical findings on the five model features. None of the policy models we examine receive the maximum score, with two of the models having a score of 4 out of 5. Indeed, the overall average is only 2.21, which suggests that much work remains to be done in connecting modelling practice in public institutions with more recent findings in the empirical literature.

There are a few survey studies on DSGE models used by public institutions, but they focus on somewhat different issues from ours. For example, Kilponen *et al*. (2019) discuss how

[3] More formally, the reasons for focusing on these household-related features can be summarized as follows. First, in the DSGE literature, social welfare is often defined as a function of households' consumption and leisure (or labor) summed over a lifetime. Thus, understanding how households adjust their consumption and labor to a policy change is crucial in policy analysis. Second, the values of household-related parameters often differ by the type of data and methods used to pin down the parameter values. For policy analysis to be credible, it is important that the adopted parameter values fall within a plausible range of the findings in academic studies. Finally, how we model households' decision on portfolio allocation (e.g., bank deposit vs stock) and the costs associated with such decisions plays an important role in determining the real-world relevance of the credit channel of monetary and fiscal policy.

DSGE models used by a few policy institutions differ from one another in model structure, while Hall *et al*. (2013) document the history and roles of macroeconomic models (including a DSGE model) used by public institutions. Compared to these studies, our contribution to the literature is threefold. First, our study encompasses an unprecedented large number of DSGE policy models (= 84) developed by 58 institutions, many of which were developed or updated after the Global Financial Crisis.[4] Second, since we incorporated a large number of models and institutions, we are able to summarize the evolution of DSGE policy models over time and across institution type and geographic region. Third, we provide a detailed comparison of model parameters related to the households by using distributions of adopted parameter values. We also discuss whether the parameter choices reflect the recent empirical literature.

The paper is constructed as follows. In the next section, we provide some background on DSGE models and the evolution of macroeconomic models used by policy institutions over time. In the third section, we describe our sample selection criterion. The fourth section provides descriptive statistics of the full sample, and the fifth section presents model comparison results using a subset of models. The sixth section concludes.

## 2. Background

### 2.1 DSGE Models Used in Academia

The main characteristics of DSGE models is that it is "micro-founded," i.e., agents optimize their behavior based on well-specified and time-invariant preference and technology parameters. The original motivation of developing such a model was to overcome the famous critique by Robert E. Lucas Jr. (Lucas, 1976). Back in the 1970s, the prevailing models used in

[4] The largest sample size in previous studies that the author is aware of is 37 by Sergi (2017).

analyzing the aggregate economy were built upon hundreds of reduced-form behavioral equations that were estimated individually. Lucas argued that policy simulations based on this type of model did not consider the possibility that the model parameters could vary in response to a policy shift.

Lucas and his followers hoped that by building a micro-founded model, policy analysis can be done in a clean lab-like environment. Since then, DSGE models gradually evolved from the simple, real business cycle model of Kydland and Prescott (1982) to the more elaborate "medium-scale" version that features multiple shocks and frictions (e.g., see Christiano *et al*., 2005 and Smets and Wouters, 2007). After the 2000s, the parameterization strategy also evolved from a simple calibration exercise to a more elaborate estimation that incorporates the Bayesian method. Meanwhile, the macroeconomic models that Lucas criticized earlier largely disappeared within the academic community by the early 2000s.

## 2.2 Types of Macro Models Used by Policy Institutions

While DSGE models quickly gained popularity among academics during the 1980s and 1990s, it is not until the 2000s that policymakers started to develop their own DSGE models. Even when DSGE models were adopted by policymakers within their institution, they were often used together with other types of models. According to Fukac and Pagan (2016), existing macroeconomic models can be broadly divided into four generations, i.e., "1G," "2G," "3G," and "4G" models. For simplicity, we re-classify them as "traditional macroeconometric models" (their 1G and 2G models combined), the "projection models" (their 3G model), and "DSGE *policy* models" (their 4G model).[5] We intentionally insert the term "policy" in between "DSGE" and

[5] The main distinction between 1G and 2G models is whether the error-correction mechanism is introduced or not, which is not crucial for our analysis. 3G models are designed for short-term forecasting. They share some features with DSGE models used in

"model" to emphasize that these models are internally developed and owned by policy institutions. We will discuss in more detail how we judge whether a model is owned by an institution later.

Figure 1 illustrates the evolution of the macroeconomic models used by policy institutions. This figure extends Pagan (2003)'s "best practice frontier," a concept that is widely shared within the policy community. The vertical axis in the figure represents how much a model honors the theoretical foundation ("theoretical coherence") while the horizontal axis represents how well the model fits the data ("empirical coherence"). The oval represents the cluster of macroeconomic models developed by policy institutions. There are two important points worth noting. First, we observe that while the traditional macroeconometric models (1G and 2G models) start out relatively high in terms of empirical coherence, later generation models (3G and 4G models) have become more "balanced" in terms of theoretical and empirical coherence. Second, the area covered by the model cluster grows larger in size, which reflects the fact that different models have been developed to meet a wider variety of policy objectives over time.[6]

## 2.3 Comparison Between DSGE and Non-DSGE Policy Models

Macroeconomic models used in policy institutions are generally tasked to do two things: forecasting and policy analysis. Each institution places different weights on them based on institutional mandate and the history of model development.

academia (stock-flow consistency, rule-based policy, presence of steady-state, multiple economic shocks, and the expectation-augmented Phillips curve). 4G models differ from 3G models in that a) economic shocks are explicitly modeled as an integral part of the model, b) adjustment cost appears directly in the primary objective functions, c) structural equations are often kept in the Euler equation form, d) solution method is shaped to account for the possible shock, and e) several types of heterogeneity are introduced in the model (Fukac and Pagan, 2016).

[6] For example, the Italian Ministry of Economy and Finance use three variants of DSGE models (IGEM, IGEM2, and IGEM-PA) to analyze different policy/forecasting issues. Bank of England possesses over 50 "suite models," which cater to its flagship DSGE model (COMPASS) in producing institutional forecast (Burgess *et al*., 2013). Further details on the objective of the DSGE policy model will be assessed in Section 4.

Table 1 summarizes the strengths and weaknesses of three types of macroeconomic models used by policy institutions based on the discussion of Hjelm *et al*. (2015). DSGE policy models have a clear advantage in policy analysis because of the strict micro-foundation that was meant to overcome the aforementioned Lucas Critique. Projections models have an advantage in short-term conditional forecasting, whereas traditional macroeconometric models are more suited for conducting sectoral analysis because of the broad coverage of the economy.[7]

DSGE models are also used for forecasting, though there is no firm consensus among practitioners about its effectiveness relative to other macroeconomic models. While the use of Bayesian estimation technique helps greatly in fitting DSGE models to the data, we also face the problem of identification as the size of the model grows bigger.[8]

In practice, international organizations and resource-rich central banks are known to utilize a "suite of models," each tailored to different policy objectives. Thus, the question of whether to develop and maintain an in-house DSGE policy model ultimately comes down to how much it costs and whether the institution can afford it.[9] Studies have reported that in order to build an in-house DSGE policy model from scratch, it roughly takes three full-time employees over two years.[10] Furthermore, division transfers, quits, and retirement pose additional challenges in keeping the model operational at all times.[11] However, DSGE policy models may have a cost

[7] Traditional macroeconometric models that are currently in use could range from the "classic" Cowles Commission type models (e.g., see Arnold, 2018) to more modern and computation-intensive types such as FRB/US (U.S. Board of Governors), LENS, IMPACT (Bank of Canada), and FR/BDF (Bank of France).

[8] As such, institutions using large-scale DSGE models with a couple of hundreds of equations often use fully calibrated models. For example, IMF uses the Global Integrated Monetary and Fiscal Model ("GIMF"), which contains thousands of model equations/variables, and all model parameters are calibrated. In the parlance of the Bayesian method, applying calibration is effectively equivalent to imposing a "degenerate" prior on the estimated parameters. On the historical origins and philosophy of the calibration method, see for example Dejong and Dave (2011).

[9] Another factor is whether the management of a policy institution understands the usefulness of DSGE policy models and has the working knowledge of applying it in the routine policy discussion.

[10] Norges Bank spent 3 years with 3 full-time equivalent (FTE) workers, the Bank of England took 2 years and 3 months with 15 FTEs, and the Finnish Ministry of Finance took 5 years with 3FTEs (Hjelm *et al*., 2015; Saxegaard, 2017). Swiss National Bank spent 2 years but with no disclosure on personnel involved (Cuche-Curti *et al*., 2009).

[11] Hjelm *et al.* (2015) points out that a model use could face particularly severe challenges when its founder(s) leaves the institution.

advantage over traditional macroeconometric models. First, DSGE models are similar in its basic structure and one can learn from other institutions that have already developed similar models. Second, the existence of commonly used programming platforms (e.g., DYNARE) makes new knowledge and structure relatively easy to be passed on within and across institutions.[12] Lastly, DSGE models are generally less costly in terms of computing power (i.e., numbers of memories, cores, and servers required to run the program within a reasonable time frame) relative to other large-scale macroeconometric models.[13]

## 3. Sample Description

### 3.1 Sample Selection Criterion

In selecting DSGE policy models, we mainly rely on manual online searches via RePEc ("Research Papers on Economics") and Google Scholar.

First, we identified 16 "key" survey papers through multiple keyword searches ("macro," "DSGE," "Policy Model," "Central Bank," and "Ministry of Finance").[14] We then used their references to initiate our own forward/backward search process. Here, "forward" search is conducted by checking the citation function in Google Scholar ("cited by") or RePEc (tab "Citation"), whereas "backward" search is conducted by directly examining the main text and reference section of the model documentations. Once we spot a new documentation that is seemingly related to a "macro" model (i.e., "DSGE," "projection," "traditional macroeconometric

[12] Other coding platforms used in DSGE model development include IRIS (Czech National Bank, Finnish Ministry of Finance), JULIA (Federal Reserve Bank of New York), MAPS (Bank of England), RISE/NB Toolbox (Norges Bank), YADA (ECB), and TROLL (IMF).
[13] For computing power required to run state-of-the-art large-scale macroeconometric models, see Hirose (2020).
[14] These papers are Blanchard (2018), Coenen *et al*. (2012), Fueki and Fukunaga (2011), Fukac and Pagan (2016), Hall *et al*. (2013), Hjelm *et al*. (2015), Kilponen *et al*. (2019), Matsumae (2012, 2017), Murphy (2017), Okano (2017), Pagan (2003, 2019), Sergi (2017), Tovar (2009), Wieland *et al*. (2012).

model") used by policy institutions, we record it and move to the next search.[15] However, overlapping generation models, VAR models, indicator models, dynamic factor models, and microsimulation models were precluded from our search.[16] After the lengthy search and recording process, we found 339 model documentations, which cover 196 macroeconomic models associated with 88 institutions.

Our next step is to examine the individual documentation and drop those that are related to either traditional macroeconometric models or projection models. It should be noted that this process is not as straightforward as one might think, since some of the modern non-DSGE macro policy models feature modelling approaches used in a conventional DSGE model used in academia (e.g., rational expectation, steady-state, partial adjustment cost, Bayesian estimation). After the thorough examination, we identified 91 DSGE policy models. The earliest DSGE model documentation in our sample was published in 2002.

### 3.2 Sample Classification

A key part of our classification is whether our sample model is owned by an institution or rather by an individual working for the institution. In the case of the latter, the model documentation should be regarded as a personal research paper. In general, it is difficult to know with certainty which of the two applies, thus we apply four criteria in judging the ownership.

The most important criterion for us is whether there is any "proper" documentation available for the model. Such documentation may take the form of peer-reviewed journal publications, institutional discussion papers, staff papers, technical notes, and slides with an

[15] One reason for casting such a wide net is because sometimes the documentation itself is not clear in whether the model should be categorized as a DSGE model or not. Also, documentation on non-DSGE models sometimes refers to DSGE models that could not have been found otherwise.
[16] Note, however, that DSGE models with overlapping generation structure is included in our sample.

institutional logo. The existence of such documentations serves as evidence that the management of the institution, who we regard as the main client of the model, is at least aware of the existence of the model. Of the 91 DSGE policy models that we identified initially, 84 accompanied at least one documentation, but for the remaining seven we could not find a proper documentation.[17] Thus we treat this sample with 84 models as our baseline sample and use them in the analysis in Section 4.

The second criterion is whether a name (typically an acronym) accompanies the model. A unique name indicates that the model development was authorized as an "internal" project by the management of the institution.[18] Among the 84 baseline sample models, 72 models have a name, but 12 did not.

The third criterion is whether the model is currently in use. This can be partially inferred from the name of the model: the model with a smaller number is (almost) always replaced by the model with a larger number. In a few cases, the model is no longer in use based on the documentation. Of the remaining 72 models, 19 models are either retired or replaced at the time of writing.

Finally, when we conduct model comparison analysis in Section 5, we further restrict our sample to one model per institution to avoid overrepresenting models from large institutions that own more than one DSGE model that are currently in use. In choosing the representative model for each institution, we pick the one with the most recent publication date. Based on these four

[17] These models are developed by National Bank of Belgium (BE-3C), Deutsche Bundesbank (BBK model), European Central Bank (NAGE), Spanish Ministry of Economy and Finance (EREMS2), Bank of France (French version of EAGLE), Bank of Lithuania's DSGE model, and International Monetary Fund (SIXMOD). We note that five of the seven institutions have developed other DSGE models that are included in the baseline sample. Therefore, we argue that our sample is unbiased for the purpose of our analysis.

[18] Furthermore, if the name accompanies either a numerical or an alphabetical extension, that serves as a strong evidence that the model is for institutional use.

criteria, our sample reduces to 42 models – which can be described as DSGE models that are owned and actively used by 42 policy institutions.[19]

## 4. Descriptive Statistics

### 4.1 Distribution of institutions by the number of models per institution

In this section, we describe our baseline sample of models by the type of institutions, the average number of authors, and stated objectives.

In our sample, a total of 58 institutions are associated with at least one of the 84 DSGE policy models.[20] Table 2 shows the distribution of institutions based on the number of models per institution. First, 34 of the sample institutions (58.6% of the total) possess only one DSGE policy model, 16 institutions (27.6%) possess two models, and the remaining eight institutions possess three or more models (13.8%). This implies that institutions that utilize a suite of DSGE models remains a minority in our sample.[21] Second, of the 58 institutions, nine engage in multi-regional (i.e. more than two regions) large-scale DSGE policy models, which we confirmed through reading the documentations. Third, of the 58 institutions, ten engage in collaborative work with other institutions, judging from the affiliation of the authors. The average number of models are 2.89 for institutions that have multi-region models and 2.60 for institutions that collaborate with others. Both numbers are notably higher than the overall average of 1.66. Finally, 30 of the 58 institutions use non-DSGE models along with DSGE policy models.

### 4.2 Average number of authors

[19] Samples chosen for this exercise are shown with asterisk in the Appendix Table A.1.
[20] These institutions consist of 37 central banks, 16 government agencies, and 5 international organizations.
[21] Appendix Table A.1 lists the institutions that have multiple DSGE policy models.

In our sample, a total of 194 documentations are associated with the 84 models. The average number of authors per documentation is 3.20, and roughly 60% of them are prepared by three or more authors. To see how the average number of authors changed over time, Table 3 sorts the model documentations by the year of publication (i.e. up to 2004, 2005-09, 2010-14, 2015-19). We see that the average number of authors per documentation has been continuously rising (2.29, 2.65, 3.26, 3.65), along with the total documentation counts in our sample (7, 48, 74, 65). The steady increase in the number of authors per documentation could be due to the increasing scale and added complexity of the model. Overall, we conclude that developing DSGE policy models involves team work and more so in recent years.

### 4.3 Stated Objectives

One possible reason that an institution owns multiple DSGE policy models is that some policy questions are best addressed using models tailored to a specific objective. To examine this, Figure 2 presents the frequency of stated objectives that appear in the model documentations.[22] Of the 58 institutions that we have examined, 48 refer to at least one objective, and 34 refer to multiple objectives in the documentation. The top 3 most frequently stated objectives are policy analysis (44 cases), forecasting (20 cases), and interpreting observed business cycles fluctuations (12 cases).

We also examined the objectives by institutional type. We find that five central banks and three international organizations mention understanding the nature of international economic linkage as one of their primary objective. Six central banks explicitly note that they use DSGE policy models to complement other macroeconomic models. And one central bank and two international organizations mention “risk analysis” as part of their objective, which is a relatively

[22] Detailed descriptions of actual stated objectives for the individual models are presented in the Appendix Table A.2.

recent phenomenon. With regard to government agencies (e.g., Ministry of Finance), the stated objectives (if any) are either policy analysis, forecasting, or interpreting business cycles, and none of them mention understanding international linkages, complementing other models, or risk analysis as their objectives.

### 4.4 Number of Models by Region and Institution Type

In our baseline sample of 84 models, 72 of them are developed by central banks and government agencies (53 institutions in total) and the remaining 12 models are developed by international organizations (five institutions in total). Table 4 tabulates the former type of models based on geographical regions (Europe, America, Asia/Oceania, Middle East/Africa) and institution types (central banks, government agencies). First, we find that close to 80% of the DSGE policy models are developed by central banks, which shows that central banks are the main users of the DSGE model.[23] Second, we find that European government agencies have the largest share among all government agencies (16 of the 17 models). The recent occurrence of the 2010 Euro Crisis could have contributed to the active development of DSGE models by European institutions.

Figure 3 depicts the number of publications broken down by year and the type of institution.[24] We witness a steady increase of DSGE model development over the years, consistent with the upward trend in the number of sample documentations seen earlier (Table 3). Part of the increase also reflects updating the existing model by incorporating the credit channel in the model developed in the pre-Global Financial Crisis era (up to 2007). However, the main push comes from the increased involvement of (mostly European) government agencies, which has increased their

[23] For non-DSGE macroeconomic models (103 models in our sample), central banks' share reduces to around 50%.
[24] The list of main reference is shown in Appendix Table A.3.

share across institution types from 10% to 24% since 2010. Many of the models developed by European government agencies simulate the effect of structural reforms augmented with rich fiscal policy options, which is likely to be motivated by the occurrence of the recent Euro Crisis.

## 5. Model Comparison

In this section, we provide model comparison based on five important model parts and parameters for the 42 models that are owned and actively used by policy institutions. In fact, the 42 models have many common model parts. Their basic structure follows the medium-scale DSGE model *a la* Smets and Wouters (2007), augmented with the small open economy assumption. Fiscal policy generally follows the tax rate rule with debt stabilization component. The total number of equations typically exceeds one hundred. The flow of technical documentations also follows similar patterns: it typically starts with the derivation of the individual model equations, then goes on to parametrization strategy, and ends with simulation results for different hypothetical scenarios using forecast error variance decomposition and/or impulse response functions.

As it turns out, much of the differences across the models occur in the treatment of the household sector. Therefore, we focus on five household characteristics: a) intertemporal elasticity of substitution for consumption ("IES"), b) habit, c) household heterogeneity, d) financial friction, and e) labor supply.[25] The difference across models can occur in terms of the choice of model parts (e.g., the type of financial frictions) and in how to parameterize the model.

### 5.1 Intertemporal Elasticity of Substitution (IES)

[25] We regard financial friction as part of household characteristics because households are the net saver in the economy which is ultimately responsible in providing loanable funds to the corporate sector (= net borrower).

One of the main features of DSGE models is the New Keynesian IS curve, which is derived by solving an intertemporal optimization problem for households' consumption. The model equation implies that consumption growth is a function of the short-term interest rate. The strength of the consumption response is represented by the IES parameter. In the academic DSGE literature, IES is usually treated as a time-invariant parameter and is often assigned a value of one, because such a parameterization will generate model predictions that are consistent with the stylized facts of long run economic growth. In empirical studies, however, this parameter is generally found to be much smaller than one, and sometimes even close to zero. Since the size of the IES is directly related to how strongly economic variables (particularly consumption) respond to exogenous shocks, assigning a large parameter value may lead to overstating the effect of policy intervention.

Figure 4(a) shows the distribution of the consumption IES parameter. 36 out of the 42 models adopt the calibration method and the remaining six use the Bayesian estimation method. Among the 36 calibrated cases, 28 adopted a value of one.[26] Figure 4(b) shows the distribution of IES for the 14 models that adopted a nonunitary value (eight are calibrated and six are estimated), and the largest mass occurs between 0.3 and 0.7. This is consistent with Havranek *et al*. (2015), which reports a mean estimate of 0.5 using the 169 academic studies in their meta-study. However, the majority of the DSGE policy models that adopted a value of one seems to be contradictory to what the recent literature has found.[27]

### 5.2 Habit

[26] More precisely, 20 models adopt the log utility, which *implies* IES of one under CRRA utility. The remaining eight set the IES parameter to be one at the parameterization stage.

[27] We further confirm that the year of the publication has nothing to do with what values of IES is adopted. The average publication year of the main reference documentation that set IES to one is 2013.9, whereas the same average for those that adopt non-unitary IES is 2013.4.

During the 1990s and early 2000s, one of the major criticisms towards DSGE models was that DSGE models were unable to replicate the "hump-shaped" responses of economic variables in response to economic shocks. To address this problem, habit formation in consumption was introduced in academic DSGE models and gradually became the norm in the early 2000's. Formally, habit formation assumes that households' utility depends on consumption exceeding the past reference level, either in external or internal form.[28] By choosing a positive value on the habit parameter, households' utility function becomes time-inseparable and history dependent. As a result, households would readjust their consumption level more gradually in response to shocks, thereby generating a seemingly realistic hump-shaped consumption response.

In our sample, 36 out of 42 models apply habit formation in consumption, of which 22 are external and 14 are internal. The remaining eight models do not incorporate any form of habit formation. Figure 5 shows the distribution of the consumption habit parameter across the 36 models. The overall sample mean is 0.67, and the largest mass occurs between 0.6 and 0.8. The mean of the calibrated habit parameter is 0.65, not much different from the mean of 0.71 for the estimated ones.

We further check whether the type of habit makes any difference. The mean estimate of the external habit parameter is 0.66, not much different from that for the internal habit (0.70). When the parameter is calibrated, the average values for both habit types are almost identical (0.71 for the external habit and 0.72 for the internal habit). When the parameter is estimated, the gap widens somewhat (0.62 for the external habit and 0.68 for the internal habit). In conclusion, the

[28] External habit applies when the consumption level of a household is compared against the overall consumption (usually lagged), which captures the effect that is often referred to as "Keeping up with the Joneses" effect. Internal habit applies when the consumption is compared across the same household at different timing. Also, note that while we focus on habit formation that applies to consumption in this paper, the concept itself can be introduced for other variables such as durables (e.g., housing), financial assets, and labor supply.

distinction between external and internal habit seems inconsequential in the choice of parameter values.

We shall note that the values adopted for the habit parameter are somewhat higher than the estimates from empirical studies. According to the meta-study by Havranek *et al*. (2017), the mean estimate of 81 studies published in academic journals is 0.43 (0.57 when aggregate data is used and 0.10 when micro-based data is used). Again, the inconsistency between DSGE policy models and empirical studies could potentially mislead policymakers in interpreting the effect of policy intervention on consumption dynamics both in terms of magnitude and persistence.

### 5.3 Heterogeneity of Households

There is a longstanding debate in macroeconomics about what proportion of households behaves rationally in a forward-looking manner ("Ricardian"). In the DSGE model setting, Ricardian households would reduce consumption in response to an expansionary fiscal shock, so that they can prepare for any future tax increase. This behavior contradicts the existing VAR results (e.g., Blanchard and Perotti, 2002) in which consumption responds positively in response to an expansionary fiscal policy.[29]

There are a few solutions offered by the academic literature. One is to introduce "hand-to-mouth (HtoM)" households, who are forced to consume all their income in the current period (Gali *et al,* 2007). By setting a sufficiently large share of HtoM households (0.25 according to Gali *et al*., 2007), the overall consumption would respond positively to an expansionary fiscal shock. Alternatively, one could also introduce heterogeneity in how people discount future utility. This can be done either by assuming a stochastic rate of death (perpetual youth model, e.g., Blanchard,

[29] Ramey (2019) notes that the bulk of the estimates for the multiplier on general government purchases on GDP lies in the range of 0.6 to 1.

1985) or a heavier future discount for borrowers relative to savers (Kiyotaki and Moore, 1997; Iacoviello, 2005). Both approaches make households behave myopic relative to the Ricardian households.

In our sample, exactly half (21 models) introduce some forms of heterogeneity among households. The breakdown is overwhelmingly in favor of the HtoM approach (19 models), followed by the perpetual youth model (3 models) and the approach of a heavier discount for borrowers (2 models). [30] Government agencies have a higher chance of incorporating heterogeneous households in their model (88%, 7 out of 8 models), relative to central banks (40%, 12 out of 30) and international organizations (50%, 2 out of 4). This is likely because consumption response to fiscal stimulus is of primary interest to government institutions.

With regard to parameterization of household heterogeneity, most institutions (86%, 18 out of 21) apply the calibration method. Figure 6 shows the distribution of the fraction of the HtoM households for the relevant 19 models. The largest mass is between 0.3 and 0.4. The calibrated values are mainly concentrated in the upper (= right) tail, whereas the estimated values are concentrated in the lower (= left) tail. More than 80% of the calibrated values exceed the threshold value of 0.25 as noted by Gali *et al*. (2007). This is counter to the generally lower values found in the empirical studies.[31] In general, one should be cautious of setting a value too high for this parameter because it could inflate the fiscal multiplier and strengthen the policy effect within the model.

### 5.4 Financial Friction

[30] Three models use combination of the two approaches.
[31] See for example, Hara *et al*. (2016), Havranek and Sokolova (2020), and Slacalek *et al*. (2020).

In traditional DSGE models, households provide funds directly to firms without any friction. This modelling strategy seemed no longer adequate after the 2008 Global Financial Crisis, during which financial intermediaries played a key role. In recent years, academics have come up with various ways to introduce financial frictions to DSGE models.[32]

In our sample, only 15 of the 42 models incorporated financial frictions of some sort. This ratio appears to be low given the importance of financial frictions emphasized by the academic communities and lively policy discussions in the post-Global Financial Crisis era. When broken down by institution type, a little over one-third of the central banks incorporated financial friction in their model (37%, 11 out of 30 models), which is somewhat higher than government agencies (25%, 2 out of 8). This finding is not surprising because the credit channel of policy transmission is perceived to be more relevant to the monetary policymaker than the fiscal policymaker.[33] With regard to the *type* of financial friction, the results are highly mixed: seven of the 15 institutions adopted the financial accelerator mechanism at the nonfinancial firm level (cf. Bernanke *et al.*, 1999), four adopted an explicit banking sector (cf. Atta-Mensah and Dib, 2008; Gerali *et al.*, 2010; Gertler and Karadi, 2011), three adopted a collateral constraint (cf. Kiyotaki and Moore, 1997; Iacoviello, 2005), and two incorporated liquidity needs for firms (cf. Christiano and Eichenbaum, 1995; Christiano *et al.*, 2008).[34] The existence of different approaches may partially explain why many of the institutions remain on the fence with regard to incorporating financial friction into their model.[35]

[32] See Christiano *et al.* (2018) for a comprehensive overview on this topic.
[33] In graduate-level textbooks, the term "credit channel" is often automatically regarded as a policy transmission channel exclusive to monetary policy. However, Yagihashi (2020) shows that the cost of credit channel misspecification in the DSGE model could be potentially larger for the fiscal policymaker relative to the monetary policymaker.
[34] One model incorporates both an Iacoviello-type financial accelerator mechanism and a Gerali *et al.*-type banking sector.
[35] Yagihashi (2018) demonstrates that the "wrong" pick of financial frictions can lead monetary policymakers to choose a suboptimal monetary policy through their misspecified model.

### 5.5 Labor Supply

One of the long-standing "puzzles" in the macroeconomic literature is that the estimate for the Frisch labor supply elasticity tends to be high when using macro data and low when using micro data.[36] In our sample, 38 out of the 42 models present the Frisch elasticity: 23 are calibrated and 15 are estimated using macro time series data.[37] Figure 7 shows the distribution of the parameter value for the 38 models both for calibrated and estimated cases. Calibrated parameters that generally use existing micro studies as their reference tend to have lower values than estimated parameters. This is consistent with the literature that generally finds larger values when using aggregate data compared with micro data.

This result also illustrates policymakers' dilemma of whether to adopt a micro-based and empirically more relevant Frisch elasticity or to estimate the parameter with the Bayesian technique that improves model fit (Section 2.3). Such a dilemma could be mitigated by introducing unemployment (= extensive margin of labor supply) into the model. Introducing unemployment can generate a large swing in aggregate hours without resorting to the implausibly large Frisch elasticity. In academic circles, two approaches have become popular in introducing unemployment: one is search and matching frictions as in Mortensen and Pissarides (1994) and the other is a utility threshold approach as in Gali *et al*. (2012).

In our sample, seven of the 38 models introduced unemployment, four of which adopted search and matching frictions and the remaining three adopted the utility threshold approach. The average Frisch elasticity when unemployment is introduced is slightly lower than the overall

[36] Chetty *et al*. (2013) conduct a meta-study on the micro-based labor supply elasticity estimates and conclude that the Frisch elasticity is likely to be less than one.
[37] Of the four remaining models, two do not explicitly model labor supply and two use the leisure-in-the-utility function approach but do not provide parameter values that allow us to calculate the implicit labor supply elasticity.

sample (0.65 as opposed to 0.82).[38] This indicates that introducing unemployment in the model can bring the macro and micro-based labor supply elasticities closer to each other without compromising model fit. But we should note that the remaining 31 models solely consider the intensive margin of labor supply.

### 5.6 A Score-card Approach for DSGE Policy Models

In the final segment, we attempt to evaluate each policy model with respect to the following five criteria that we have examined so far:

1. Does the model adopt nonunitary value for the consumption IES?
2. Does the model allow habit formation in consumption?
3. Does the model introduce heterogeneity in households?
4. Does the model incorporate financial frictions?
5. Does the model include unemployment?

For the sake of simplicity, the model scores one point for each "yes" to the above questions, that is, the maximum score is a five.[39]

Figure 8 shows the distribution of scores for our baseline sample of 42 models. No institution receives the maximum score of five and only two models score four points.[40] While there is no model that scores a zero, as much as nine models score a meager one point (21.4% of the total). The overall average score is 2.21. This seemingly low average score indicates that the

[38] Chetty *et al*. (2013) report that in their sample the unweighted mean for the extensive-margin Frisch elasticity is 0.32. Combined with the intensive-margin Frisch elasticity ranging from 0.37 to 0.7, the overall Frisch elasticity of aggregate hours would add up to 0.69-1.02.

[39] Note that we are not trying to argue that the stated five criteria are *equally* important to all DSGE models because the institution may have different objectives and emphasis. We simply evaluate whether the DSGE policy models incorporated recent academic findings.

[40] The two highest scoring models are BoC-GEM-Fin developed by Bank of Canada and FiMod developed jointly by Banco de Espana and Deutsche Bundesbank.

five criteria may be controversial within the policy community. Furthermore, there is no clear winner in terms of institution type: the average scores of central banks, government agencies, and international organizations are 2.23, 2.13, and 2.25, respectively.

One possible explanation is that only resource-rich institutions can afford a DSGE model that meet all of our criteria. Using the number of DSGE models owned by an institution as a proxy for resource-rich institutions, we find that the correlation coefficient between the number of DSGE models of a given institution and the score of its representative DSGE model is 0.327, which shows mild positive association. Another possible explanation is that newer models have an advantage over older models in terms of incorporating new modeling techniques. The correlation coefficient between the year of publication of the main reference documentation and the score is 0.169. While the hypothesis of the late-mover advantage is confirmed, the association seems much lower than one would anticipate.

Table 5 reports the correlation coefficients between a given pair of evaluation criteria, which represents how likely the two model parts are chosen together. We find positive correlation coefficients in three out of the possible ten cases, indicating that the relevant model parts tend to be chosen together. These are non-unitary IES and heterogeneous households (corr. coef. = 0.20), habit formation and unemployment (0.18), and heterogeneous households and unemployment (0.06). There are two interpretations for the observed positive associations. First, it may simply reflect the sequence of model updates, which parallels model development in the academic DSGE literature. Second, the positive signs show that the model parts are complementary in nature, i.e., need both of them to yield the anticipated model outcome.

## 7. Conclusions

This paper surveys recent DSGE models used by public institutions around the world using publicly available documentations. We show that over the years there is a steady increase in the development of DSGE models by policy institutions, particularly among Europeans and after the 2008 Global Financial crisis. Many institutions have multiple DSGE models serving different purposes. Over time, DSGE models have also become more complex and involve more researchers in model development.

Although the use of DSGE models among policy institutions has been growing, consensus has been hardly reached on modelling practice. We demonstrate this by comparing model features along five dimensions using 42 models from policy institutions. We find large variations in both modelling strategies and adopted parameter values, some of which do not reflect the findings of the recent empirical literature. We conclude that there is a great need for future DSGE policy models to adopt more recent academic findings in order to continue serving as a credible tool for policymaking.

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## Appendix

Table A.1: Institutional Rankings Based on the Number of DSGE Policy Models They Own

| # of Models | Institution (Country) | Use non-DSGE Models? |
|---|---|---|
| 5 | Banca d' Italia (ITA) | yes |
| 4 | European Central Bank | yes |
| | International Monetary Fund | yes |
| | The Bank of Finland (FIN) | no |
| | Federal Reserve Bank of NY (USA) | no |
| 3 | Banco de Espana (ESP) | yes |
| | Ministry of Economy & Finance (ITA) | yes |
| | Banco de Portugal (POR) | no |
| 2 | Bank of Canada (CAN) | yes |
| | Deutsche Bundesbank (DEU) | yes |
| | Spanish Ministry of Economy and Finance (ESP) | yes |
| | Reserve Bank of New Zealand (NZL) | yes |
| | Sveriges Riksbank (SWE) | yes |
| | Federal Reserve Board (USA) | yes |
| | European Commission | no |
| | Central Bank of Chile (CHL) | no |
| | SEPG (ESP) | no |
| | Ministry of Finance and Public Administration (ESP) | no |
| | SEEAE (ESP) | no |
| | Luxembourg Ministry of Economy and Trade (LUX) | no |
| | Central Bank of Malta (MLT) | no |
| | National Bank of Poland (POL) | no |
| | National Bank of Slovakia (SVK) | no |

Note: The rankings are based on the baseline sample of 84 models. To save space, we only list institutions that have two or more DSGE models. Non-DSGE macro models refer to either traditional macro models or projection models, which are confirmed via their documentations.

Table A.2: Stated Objective for DSGE Policy Models

| Country/Institution | | Statement |
|---|---|---|
| AUS | Reserve Bank of Australia | "The model is part of a set of macroeconomic models maintained by the Economic Research Department at the RBA. These models complement, but do not substitute for, the more detailed sectoral analysis and judgement-based projections."; "The model can be used to provide scenario and sensitivity analysis. It also provides a crosscheck on forecasts produced by reduced-form econometric techniques and judgement." (Rees *et al*., 2016) |
| BRA | Banco Central do Brazil | "The current BCB macroeconomic modeling framework comprises a suite of models, including small and medium-size semi-structural models, vector autoregression (VAR) models and auxiliary structures that are used to answer specific policy issues. The DSGE model is an important additional tool to that framework." (de Castro *et al*., 2015) |
| CAN | Bank of Canada | "Bank staff have used the BoC-GEM to analyze various issues and to model how those issues could affect Canada either directly or indirectly." (Bailliu *et al*., 2010); "We use BoC-GEM-FIN to study the effects of countercyclical bank capital requirements on macroeconomic stability in the U.S." (deResende *et al*., 2016) |
| CHE | Swiss National Bank | "The model is expected to serve as a laboratory for a) studying business cycles in Switzerland, b) examining the effects of actual and hypothetical monetary policies, and c) projecting (forecasting) the likely course of events – under various scenarios – for the Swiss economy in the short to medium term." (Cuche-Curti *et al.*, 2009) |
| CHL | Central Bank of Chile | "The Central Bank of Chile has been using dynamic stochastic general equilibrium (DSGE) models for regular policy analysis and medium-term projections for its Monetary Policy Report since the late 2000s" (Garcia *et al.*, 2019) |
| COL | Bank of the Republic (Columbia) | "PATACON was designed to be useful for analyzing Colombian macroeconomic data and to help guide monetary policy discussion." (Gonzalez *et al*., 2012) |
| CZE | Czech National Bank | "The new structural model (g3) has been used as the core forecasting tool since July 2008." (Andrle *et al*., 2009) |
| CZE | Ministry of Finance of the Czech Republic | "The Ministry of Finance of the Czech Republic has developed an extended version of the DSGE model. It serves various purposes. It primarily supports macroeconomic forecasts by evaluating model scenarios on a quarterly basis. Moreover, the model is employed for simulation purposes related to changes in fiscal policy parameters, and also for assessing the sensitivity of macroeconomic variables to various shocks to the economy." (Aliyev *et al*., 2014) |
| DEU | Deutsche Bundesbank | "We use the model to assess how discretionary fiscal policy in Germany and the Euro Area affected GDP growth during the crisis, evaluate spillovers of fiscal policy and calculate various present-value multipliers for distinct fiscal instruments." (Gadatsch *et al.*, 2016) |
| ESP / DEU | Banco de Espana / Deutsche Bundesbank | "The model has been used for policy simulations in the Working Group on Econometric Modelling (WGEM) of the European System of Central Banks (ESCB)." (Staehler and Thomas, 2012) |

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| ESP | Banco de Espana | "In particular, a version of this model is expected to be used in the near future to run simulations and alternative scenario analysis for the Spanish economy within the forecast process. Therefore, one of the requirements of the model is to replicate the developments of most of the variables included in the Spanish Quarterly National accounts, which is why the model structure is more elaborated than what is standard in the literature." (Andres *et al.*, 2006) |
| ESP | Spanish Ministry of Economy and Finance | "In the last eight years, the REMS model has become one of the reference tools used by different institutions for ex-ante macro evaluation of the effects of a number of policies and shocks affecting the Spanish economy." (Bosca and Ferri, 2016) |
| ESP | Economic Office of the President of Spain | "MEDEA is a dynamic stochastic general equilibrium (DSGE) model that aims to describe the main features of the Spanish economy for policy analysis, counterfactual exercises, and forecasting." |
| EST | Bank of Estonia | "One of the main goals of building a DSGE model for Estonia is to use it to understand the monetary policy and export-import linkages between a small open economy of Estonia and the much bigger euro area economy. The list of other potential uses of the new model includes simulation exercises, policy advice and forecasting of the main macroeconomic aggregates." (Gelain and Kulikov, 2009) |
| EU | European Central Bank | "…aim pursued in the development of NAWM2… to provide a structural framework useable for assessing the macroeconomic impact of the ECB's large-scale asset purchases…" (Coenen *et al.*, 2018) |
| EU / PRT / ITA | European Central Bank / Bank of Portugal / Bank of Italy | "The model (EAGLE, Euro Area and Global Economy model) is microfounded and designed for conducting quantitative policy analysis of macroeconomic interdependence across regions belonging to the euro area and between euro area regions and the world economy." (Gomes *et al.*, 2012); "Our results aim at explaining the domestic and cross-country transmission mechanism of various shocks in a monetary union model where financial factors do matter.", "…EAGLE-FLI allows us to conduct a quantitative analysis in a theoretically coherent and fully consistent model setup, clearly spelling out all the policy implications." (Bokan *et al*., 2018) |
| EU | European Commission | "Specifically, the GM model has been developed for three main purposes, namely (1) the structural interpretation of business cycle dynamics, (2) contributions to the European Commission's economic forecast, and (3) scenario analysis and policy counterfactuals" (Albonico *et al.*, 2019); "QUEST is the global macroeconomic model that the Directorate General for Economic and Financial Affairs (DG ECFIN) uses for macroeconomic policy analysis and research.", "Model variants have been estimated using Bayesian methods, jointly with colleagues at the Commission's Joint Research Centre (JRC). These dynamic stochastic general equilibrium (DSGE) models are used for shock analyses and shock decompositions, for example, to assess the main drivers of growth and imbalances." (retrieved from the EC website on May 15, 2020) |
| EU | European Stability Mechanism | "We present EIRE Mod, a quarterly DSGE model developed for macroeconomic policy analysis in Ireland." (Clancy and Merola, 2016) |
| FIN | Bank of Finland | "Since the fall of 2015, Aino2.0 has been used as the main forecasting model of the Bank of Finland."; "To be clear, Aino 2.0 is by no means the |

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| | | only input into the forecasting and policy processes at the Bank of Finland; several other models are also used." (Kilponen *et al.*, 2016) |
| FIN | Finnish Ministry of Finance | "In-house was chosen? Why? 1) Need to increase human capital 2) Commitment 3) Continuity." (Kuismanen, 2016) |
| GBR | Bank of England | "COMPASS is intended to serve three key purposes: to be the main organizing framework for the construction of the forecast; to analyse and explain the forecast (projection analysis); and to construct experiments to assess the sensitivity of the forecast to alternative assumptions (scenario analysis)." (Burgess *et al.*, 2013) |
| GRC | Bank of Greece | "… developed at the Bank of Greece as a quantitative tool for policy analysis." (Papageorgiou, 2014) |
| HUN | Central Bank of Hungary | "PUSKAS was used in monetary policy decision support to produce historical shock decompositions, enabled the carrying out of welfare analysis and was able to perform counterfactuals without exceedingly abusing the Lucas Critique." (Szilagyi *et al.*, 2013) |
| IMF | International Monetary Fund | "The Global Integrated Monetary and Fiscal Model (GIMF) is a multi-region, forward-looking, DSGE model developed by the Economic Modeling Division of the IMF for policy analysis and international economic research." (Anderson *et al.*, 2013); "… used by the IMF for a variety of tasks including policy analysis, risk analysis, and surveillance." (Kumhof *et al.*, 2010); "MAPMOD has been designed specifically to study vulnerabilities associated with excessive credit expansions and asset price bubbles, and the consequences of different macroprudential policies that attempt to guard against or cope with such vulnerabilities." (Benes *et al.*, 2014) |
| ISL | Central Bank of Iceland | "The model has been developed at the Central Bank of Iceland as a tool in support of inflation targeting." (Seneca, 2010) |
| ISR | Bank of Israel | "a. To provide a basis for discussion"; "b. Now casting and forecasting"; c. To evaluate alternative policy measures and economic scenarios." (Argov *et al.*, 2012) |
| ITA | Bank of Italy | "… evaluates the macroeconomic effects of the corporate sector purchase programme (CSPP) implemented in the euro area by the Eurosystem." (Bartocci *et al.*, 2017) |
| ITA | Department of the Treasury, Ministry of Economy and Finance, Italy | "Notably, IGEM has been designed to study the impact and the propagation mechanism of temporary shocks, evaluate the impact of alternative structural reform scenarios and analyze the effects of single policy interventions and fiscal consolidation packages in Italy." (Annicchiarico *et al.*, 2016); "With this new variant of IGEM we are able to answer the following economic policy questions. Which are the macroeconomic effects of the rationalization of public spending? Which are the implications of major advances in the implementation of the digital agenda? How do the simplification reforms impact on the economy when the PA sector is explicitly modeled? What happens if the overall productivity of the public sector increases?" (Annicchiarico *et al.*, 2017) |
| IRL | ESRI/Ministry of Finance, Ireland | "The primary aim of FIR-GEM is to serve as a fiscal policy toolkit for fiscal policy analysis in Ireland." (Varthalitis, 2019) |
| LUX | Ministry of the Economy and Foreign Trade | "The resulting model is then calibrated to match the specific characteristics of the Luxembourg economy, and used to assess the consequences of a series of policies targeting the financial sectors."; "This is the distinctive |

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| | | feature of LSM2, which makes it more suitable than the other models for policy simulations, though perhaps less adapted to other uses, such as short and medium-term forecasting." (Deak *et al*., 2012) |
| MLT | Central Bank of Malta | "… this paper presents a unifying framework to quantify the impact of structural reforms aimed at increasing competition in Malta's product and labour markets using a dynamic stochastic general equilibrium (DSGE) model." (Micallef, 2019); "This model, together with its future extensions, is meant to be used as a complement to existing policy analysis tools available at the Central Bank of Malta." |
| NOR | Norges Bank | "NEMO has been used to identify the sources of business cycle fluctuations in Norway, to conduct scenario analysis, to produce macroeconomic forecasts, and to conduct monetary policy analysis."; "Starting from 2018, the model has also been used for macro-prudential stress testing." (Kravik and Mimir, 2019) |
| NZL | Reserve Bank of New Zealand | "NZSIM provides the platform for the Bank's medium term economic analysis and scenario testing during the monetary policy making process." (Austin and Reid, 2017) |
| PER | Central Reserve Bank of Peru | "The main objective of this model is to conduct policy analysis, namely forecast and simulations conditional on the behavior of monetary (and/or fiscal) policy. Also, the model structure can be used to decompose macroeconomic variables on the factors that explain their fluctuations." (Florian and Montoro, 2009) |
| PHL | Central Bank of Philippines | "BSP's DSGE model acts as a complement to existing models used by the BSP for policy simulation." (Reyes *et al*., 2017) |
| POL | National Bank of Poland | "In 2009, a team consisting of the authors of this paper developed a new version of the model, called $SOE^{PL\text{-}2009}$ which in 2010 is to be used to obtain routine mid-term forecasts of the inflation processes and the economic trends, supporting and supplementing the traditional structural macroeconometric model and experts' forecasts applied so far."; "We pass the DSGE $SOE^{PL\text{-}2009}$ model for use, with a view to considering and analyzing other interpretation and understanding of economic processes than that proposed by the traditional models. Additionally, systematic work with the model (preparing forecasts and analyses of their accuracy, simulation experiments and analytical works) may reveal issues and problems that will have to be solved." (Grabek *et al*., 2011) |
| PRT | Banco de Portugal | "… the model is used to assess the impact of a number of shocks that played an important role in Portugese economic developments,…"; "… provide well-grounded support for structural reforms in Portugal,…"; "… evaluate the impact of fiscal stimulus in a small open economy within a monetary union,…"; "used to show that a fiscal consolidation strategy based on a permanent reduction in Government expenditure increases the long-run level of output, private consumption and welfare, at the cost of short-run welfare losses and output reduction."; "evaluate the size of short-run fiscal multipliers associated with fiscal consolidation under two distinct alternative scenarios, *viz* "normal times" and "crisis times."" (Almeida *et al*., 2013) |
| SRB | National Bank of Serbia | "Regarding its role in policy making at the NBS, the DSGE model is to be used mainly as a policy analysis tool rather than for forecasting…" (Djukic *et al*., 2017) |
| SVK | National Bank of Slovakia | "The National Bank of Slovakia, as a member of the Eurosystem, participates in policy discussions covering the entire euro area. While its |

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| | | main objective is still to evaluate the effects of different policies and impacts of shocks in the Slovak economy, the Slovak central bank is now more interested in the evaluation of these effects on the whole euro area. This motivation leads us to develop a two-country model in which countries form a monetary union." (Senaj *et al*., 2010) |
| SWE | Sveriges Riksbank | "The model is used to produce macroeconomic forecasts, to construct alternative scenarios, and for monetary policy analysis." (Adolfson *et al*., 2013) |
| THA | Bank of Thailand | "The purpose of this DSGE model is to provide a coherent economic interpretation of the workings of the Thai economy consistent with microeconomic foundation"; "We at the Bank of Thailand believe that, in addition to providing state-of-the-art tools, DSGE models will help stimulate central bank research, provide an effective framework for monetary policy analysis and forecasting, and promote further insights into the workings of the economy." (Tanboon, 2008) |
| USA | Federal Reserve Board | "… we note that the EDO model serves as a complement to the analyses that are currently performed using existing large-scale econometric models, such as FRB/US model, as well as smaller, *ad hoc* models that we have found useful for more specific questions."; "In addition, the EDO model is designed to allow the straightforward consideration of factors not explicitly modeled in the baseline version of the model." (Chung *et al*., 2010); "In this paper, we describe a new multicountry open economy SDGE model named "SIGMA" that we have developed as a quantitative tool for policy analysis." (Erceg *et al*., 2006); "In this paper, we use a DSGE model (SIGMA) to show that taking account of the expenditure composition of U.S. trade in an empirically realistic way yields implications for the responses of trade to shocks that are markedly different from those of a 'standard' framework that abstracts from such compositional differences." (Erceg *et al*., 2008) |
| USA | Federal Reserve Bank of New York | "The New York Fed DSGE model came to existence around 2004 as a three-equation New Keynesian model (see Sbordone et al., 2010). At that time, the model was used for a variety of policy analysis exercises but not for forecasting."; "In mid-2010, the model began to be used internally for forecasting the U.S. economy, …"; "The model built in 2010, which is described in some detail in Del Negro *et al*. (2013), continued to be the main workhorse for DSGE projections and policy analysis at the NY Fed until the end of 2014." (Cai et al., 2019) |
| USA | Federal Reserve Bank of Chicago | "The Chicago Fed dynamic stochastic general equilibrium (DSGE) model is used for policy analysis and forecasting at the Federal Reserve Bank of Chicago. This article describes its specification and estimation, its dynamic characteristics and how it is used to forecast the US economy." (Brave *et al*., 2012) |

Table A.3: List of Models, Associated Institutions and References

(a) National Government

| Name | Country | Institution/Division | Main Reference |
|---|---|---|---|
| RBA-DSGE* | AUS | Reserve Bank of Australia, Econ. Research | Rees *et al.* (2016) |
| SAMBA* | BRA | Central Bank of Brazil | de Castro *et al.* (2015) |
| BoC-GEM-FIN* | CAN | Bank of Canada Intl. Econ. Analysis Dept. | de Resende *et al.* (2016) |
| BoC-GEM | CAN | Bank of Canada Intl. Econ. Analysis Dept. | Lalonde and Muir (2007) |
| DSGE-CH* | CHE | Swiss National Bank | Cuche-Curti *et al.* (2009) |
| XMAS* | CHL | Central Bank of Chile | Garcia *et al.* (2019) |
| MAS | CHL | Central Bank of Chile | Medina and Soto (2007) |
| PATACON* | COL | Bank of the Republic (Columbia) | Gonzalez *et al.* (2011) |
| HUBERT3* | CZE | Ministry of Finance of the Czech Republic | Aliyev *et al*. (2014) |
| g3* | CZE | Czech National Bank | Andrle *et al.* (2009) |
| GEAR* | DEU | Deutsche Bundesbank (BUBA) | Gadatsch *et al.* (2016) |
| (no name) | DNK | Danmarks Nationalbank | Pedersen (2016) |
| REMS1* | ESP | Spanish Ministry of Economy and Finance, joint with SEPG, MoFPA, and SEEAE | Bosca and Ferri (2016) |
| REMS | ESP | Spanish Ministry of Economy and Finance, joint with SEPG, MoFPA, and SEEAE | Bosca *et al.* (2010) |
| MEDEA* | ESP | Economic Office of the President of Spain | Burriel *et al.* (2010) |
| FiMOD* | ESP/DEU | Banco de Espana, joint with Deutsche Bundesbank | Stähler and Thomas (2012) |
| BEMOD | ESP | Banco de Espana | Andres *et al*. (2006) |
| EP-DSGE* | EST | Bank of Estonia | Gelain and Kulikov (2009) |
| AINO2* | FIN | Bank of Finland | Kilponen *et al.* (2016) |
| AINO | FIN | Bank of Finland | Kilponen and Ripatti (2006) |
| EDGE | FIN | Bank of Finland | Kortelainen (2002) |
| KOOMA* | FIN | Ministry of Finance (Finland) | Elmgren (2017), Ministry of Finance (2013, code); |
| OMEGA3* | FRA | French Ministry for the Economy and Finance, joint with DGTPE | Carton and Guyon (2007) |
| COMPASS* | GBR | Bank of England | Burgess *et al.* (2013) and its accompanying appendix |
| BoGGEM* | GRC | Bank of Greece | Papageorgiou (2014) |
| (no name) | HKG | Hong Kong Monetary Authority, Research Dept. | Cheng and Ho (2009) |
| PUSKAS* | HUN | Central Bank of Hungary | Jakab *et al.* (2010) |
| (no name) | HUN | Office of Fiscal Council | Baksa *et al.* (2010) |
| FIR-GEM* | IRL | Department of Finance (Ireland), joint with ESRI, Revenue Commissioners | Varthalitis (2019) |

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|---|---|---|---|
| (no name) | ISL | Central Bank of Iceland | Seneca (2010) |
| MOISE* | ISR | Bank of Israel, Research Dept. | Argov *et al.* (2012) |
| IGEM2* | ITA | Ministry of Economy & Finance, Dept. of Treasury | Annicchiarico *et al.* (2016) |
| IGEM | ITA | Ministry of Economy & Finance, Dept. of Treasury | Annicchiarico *et al.* (2013) |
| IGEM-PA | ITA | Ministry of Economy & Finance, Dept. of Treasury | Annicchiarico *et al.* (2017) |
| NAWM (Italy ver.)* | ITA | Banca d'Italia | Bartocci *et al.* (2017) |
| IDEA-BI-EAGLE | ITA | Banca d'Italia | Forni *et al.* (2010) |
| (no name) | ITA | Banca d'Italia | Darracq Paries and Notarpietro (2008) |
| M-JEM* | JPN | Bank of Japan Research Dept. | Fueki *et al.* (2016) |
| (no name) | JPN | Government of Japan Cabinet Office ESRI | Matsumae and Hasumi (2016) |
| LSM2* | LUX | Luxembourg Min. of Economy & Trade | Deak *et al.* (2012) |
| LSM | LUX | Luxembourg Min. of Economy & Trade | Deak *et al.* (2011) |
| (no name) | LVA | Latvia Banca | Ajevskis and Vitola (2011) |
| EAGLE (Malta ver.)* | MLT | Central Bank of Malta, Research Dept. | Micallef (2019) |
| MEDSEA | MLT | Central Bank of Malta, Research Dept. | Rapa (2016) |
| (no name) | NLD | De Nederlandsche Bank (DNB) | Lafourcade and Wind (2012) |
| NEMO* | NOR | Norges Bank | Kravik and Mimir (2019) |
| NZSIM* | NZL | Reserve Bank of New Zealand | Kamber *et al.* (2016) |
| KITT | NZL | Reserve Bank of New Zealand | Benes (2010) |
| MEGA-D* | PER | Central Reserve Bank of Peru | Florian and Montoro (2009) |
| BSP's DSGE model* | PHL | Central Bank of Philippines | McNelis *et al.* (2010) |
| SOEPL-2012* | POL | National Bank of Poland | Grabek and Klos (2013) |
| SOEPL-2009 | POL | National Bank of Poland | Grabek *et al.* (2011) |
| PESSOA* | POR | Banco de Portugal | Almeida *et al.* (2013) |
| R.E.M. 2.0* | ROU | National Bank of Romania | Copaciu *et al.* (2015) |
| (no name) | SRB | National Bank of Serbia | Djukic *et al.* (2017) |
| MUSE* | SVK | National Bank of Slovakia | Senaj *et al.* (2010) |
| DSGE Model-Slovakia | SVK | National Bank of Slovakia | Zeman and Senaj (2009) |
| (no name) | SVK | Council for Budget Responsibility | Mucka (2016) |
| RAMSES2* | SWE | Sveriges Riksbank, Mon. Policy Dept. | Adolfson *et al.* (2013) |
| RAMSES | SWE | Sveriges Riksbank, Mon. Policy Dept. | Christiano *et al.* (2011) |
| BOT DSGE* | THA | Bank of Thailand | Tanboon (2008) |

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|---|---|---|---|
| EDO | USA | Federal Reserve Board | Chung *et al.* (2010) |
| SIGMA | USA | Federal Reserve Board | Erceg *et al.* (2008) |
| SWFF++* | USA | Federal Reserve Bank of New York | Cai *et al.* (2019) |
| SWFF+ | USA | Federal Reserve Bank of New York | Cai *et al.* (2019) |
| SWFF | USA | Federal Reserve Bank of New York | Del Negro *et al.* (2015) |
| NY Fed DSGE Model | USA | Federal Reserve Bank of New York | Del Negro *et al.* (2013) |
| Chicago Fed DSGE Model | USA | Federal Reserve Bank of Chicago | Brave *et al.* (2012) |
| (no name) | ZAF | South African Reserve Bank | duPlessis *et al.* (2014) |

(b) International Organization

| Name | Institution | Reference |
|---|---|---|
| GIMF* | International Monetary Fund Research Dept. | Kumhof *et al.* (2010) |
| MAPMOD | International Monetary Fund Research Dept. | Benes *et al.* (2014) |
| GEM | International Monetary Fund Research Dept. | Everaert and Schule (2008) |
| GFM | International Monetary Fund Research Dept. | Botman *et al.* (2006) |
| SIXMOD | International Monetary Fund Research Dept. | (no docs) |
| GM3-EMU* | European Commission DG ECFIN, joint with JRC | Albonico *et al.* (2019) |
| QUEST3 | European Commission DG ECFIN | Ratto *et al.* (2009) |
| NAWM2* | European Central Bank | Coenen *et al.* (2018) |
| NAWM | European Central Bank | Christoffel *et al.* (2008) |
| NAGE | European Central Bank | (no docs) |
| EAGLE-FLI | European Central Bank, joint with Bank of Italy, Bank of Portugal | Bokan *et al.* (2018) |
| EAGLE | European Central Bank, joint with Bank of Italy, Bank of Portugal | Gomes *et al.* (2012) |
| EIRE Mod* | European Stability Mechanism | Clancy and Merola (2016b) |
| (no name) | Organization for Economic Cooperation and Development | Cacciatore *et al.* (2012) |

Note: * indicates the model is used in the model comparison exercise of Section 5.

## Appendix Reference


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Table 1: Comparison of DSGE Models and Other Macroeconometric Models

| Model | Policy Analysis | Fore-cast | Cost to develop | Cost to maintain |
|---|---|---|---|---|
| DSGE Policy Model | A | C | C | B |
| Projection Model | C | B | A | A |
| Traditional Macro Model | B | C | D | D |

Note: The table is constructed based on the discussion in Hjelm *et al.* (2015) as well as our own opinion: the letters refer to A (desirable/easy/low cost) to D (not adequate/hard/high cost).

Table 2: Distribution of Institutions Based on the Number of Models per Institution

| Number of models per institution | Number of institutions (% of total) | of which own multi-regional DSGE model | of which collaborate with others | of which non-DSGE models are additionally used |
|---|---|---|---|---|
| 1 | 34 (58.6%) | 0 | 1 | 19 |
| 2 | 16 (27.6%) | 5 | 5 | 6 |
| 3 | 3 (5.2%) | 1 | 2 | 2 |
| 4 | 4 (6.9%) | 2 | 1 | 2 |
| 5 | 1 (1.7%) | 1 | 1 | 1 |
| Total # of inst. | 58 (100.0%) | 9 | 10 | 30 |
| Average # of models per institutions | 1.66 | 2.89 | 2.60 | 1.67 |

Note: The sample includes 58 institutions that appear in our baseline sample of 84 models.

Table 3: Distribution of Documentations Based on the Number of Authors

| Number of authors per documentation | Published between 2000-19 (% of total) | Up to 2004 | 2004 to 2009 | 2010 to 2014 | 2015 to 2019 |
|---|---|---|---|---|---|
| 1 | 29 (15%) | 2 | 5 | 9 | 13 |
| 2 | 52 (27%) | 2 | 17 | 22 | 11 |
| 3 | 51 (26%) | 2 | 18 | 20 | 11 |
| 4 | 38 (20%) | 1 | 6 | 12 | 19 |
| 5 | 10 (5%) | 0 | 2 | 3 | 5 |
| 6 and up | 14 (7%) | 0 | 0 | 8 | 6 |
| Tot. # of docs | 194 (100%) | 7 | 48 | 74 | 65 |
| Ave. # of authors per documentation | 3.20 | 2.29 | 2.65 | 3.26 | 3.65 |

Note: The sample includes 194 documentations that are associated with our baseline sample of 84 models.

Table 4: The Number of DSGE Policy Models by Region and Institution Type

| | Europe | America | Asia /Oceania | ME /Africa | Total |
|---|---|---|---|---|---|
| Central banks | 32 | 14 | 7 | 2 | 55 |
| Government agencies | 16 | 0 | 1 | 0 | 17 |
| Ministries | 12 | 0 | 0 | 0 | 12 |
| Other agencies | 4 | 0 | 1 | 0 | 5 |
| Total | 48 | 14 | 8 | 2 | 72 |

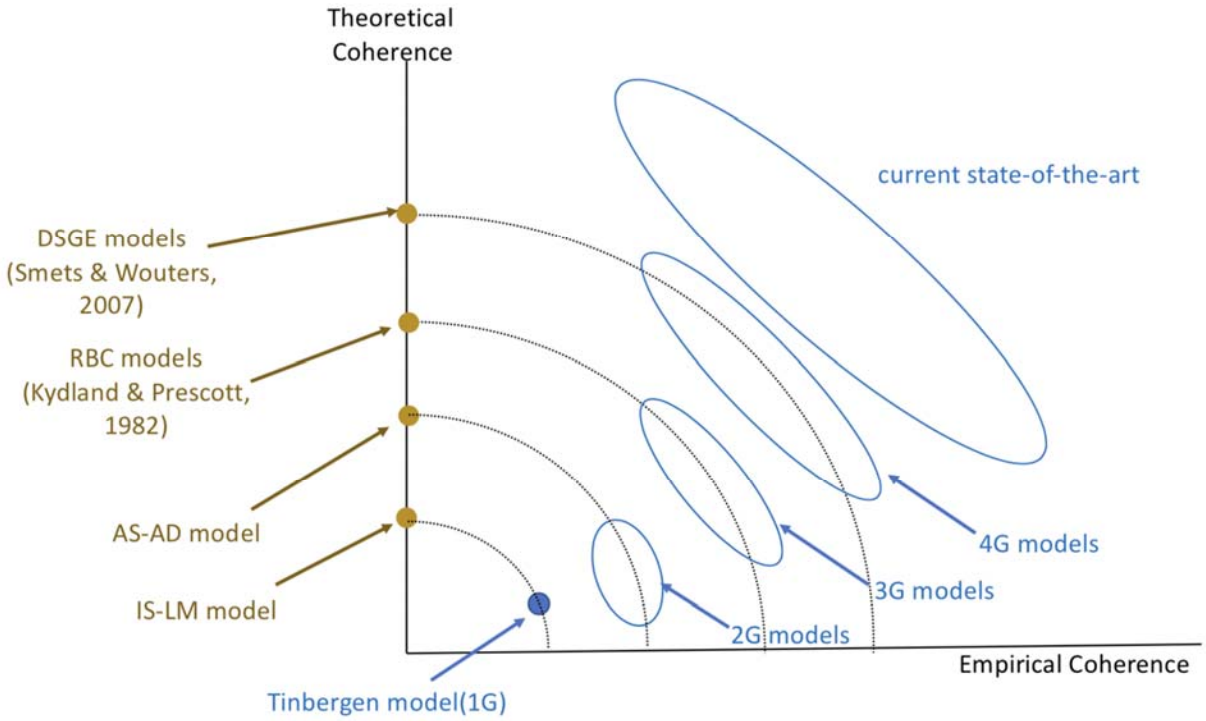
Note: The sample includes 72 models that are owned by either central banks or government agencies (i.e. 12 models developed by international organizations are excluded). The term "Other agencies" include statistical office, national head's office, and independent fiscal institutions.

Table 5: Pairwise Correlation

| Samples | Non-unitary IES | Habit forma-tion | Hetero-geneous HH | Finan-cial friction | Un-employ-ment |
|---|---|---|---|---|---|
| Nonunitary IES | 1.00 | | | | |
| Habit formation | -0.14 | 1.00 | | | |
| Heterogeneous household | 0.20 | -0.27 | 1.00 | | |
| Financial friction | -0.11 | -0.26 | -0.15 | 1.00 | |
| Unemployment | -0.18 | 0.18 | 0.06 | -0.07 | 1.00 |

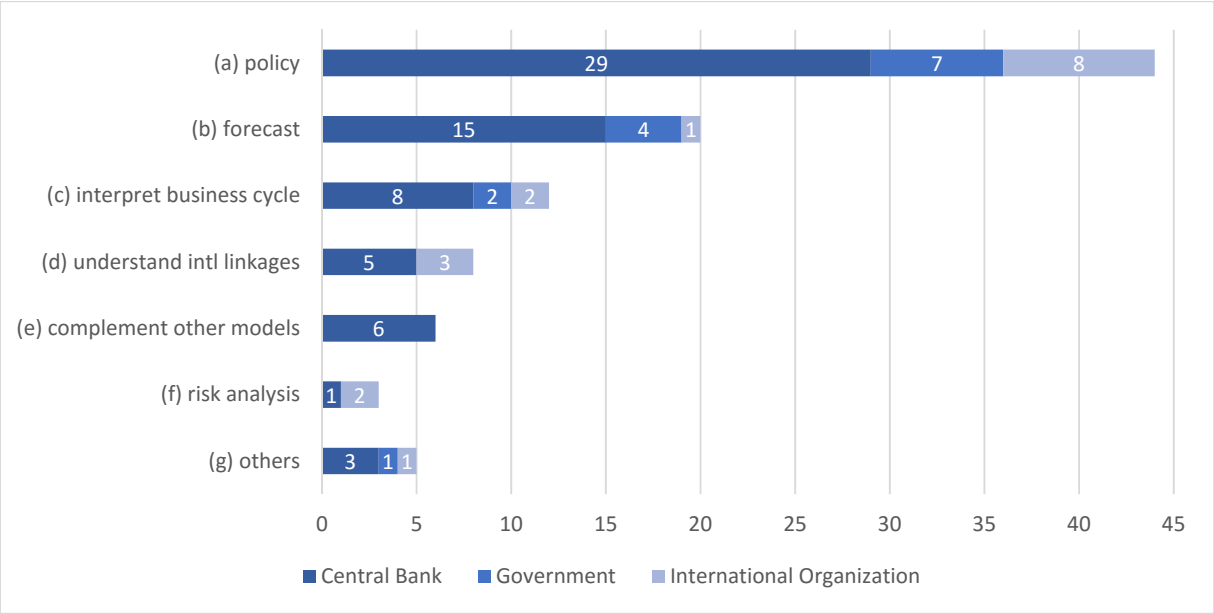
Note: The sample includes 42 models that are used in the model comparison exercise in Section 5.

Figure 1: Development of Macroeconomic Models



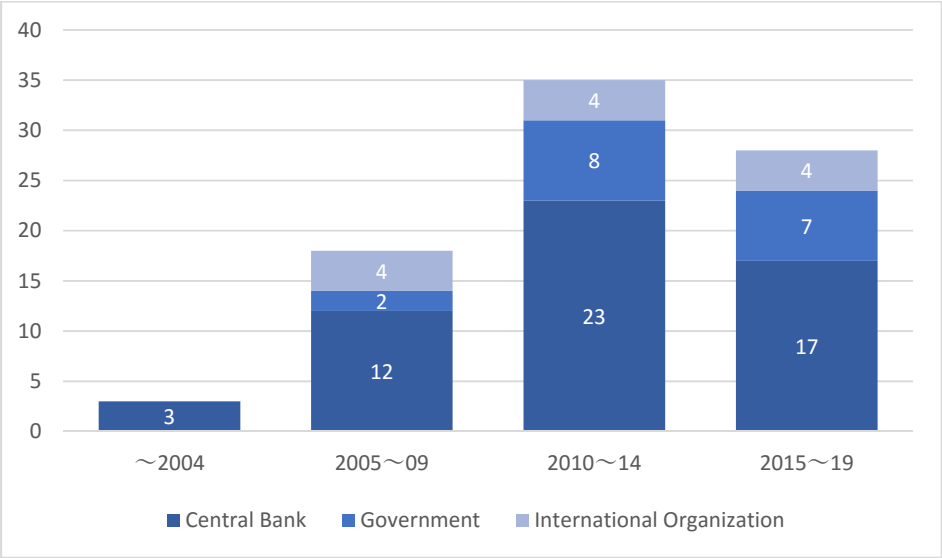

Note: The vertical axis represents how much a model honors the theoretical foundation while the horizontal axis represents how well the model fits the data. 1G, 2G, 3G, 4G represent the distinct generations of macroeconomic models as defined in Fukac and Pagan (2016).

Figure 2: Stated Objectives of DSGE Policy Models



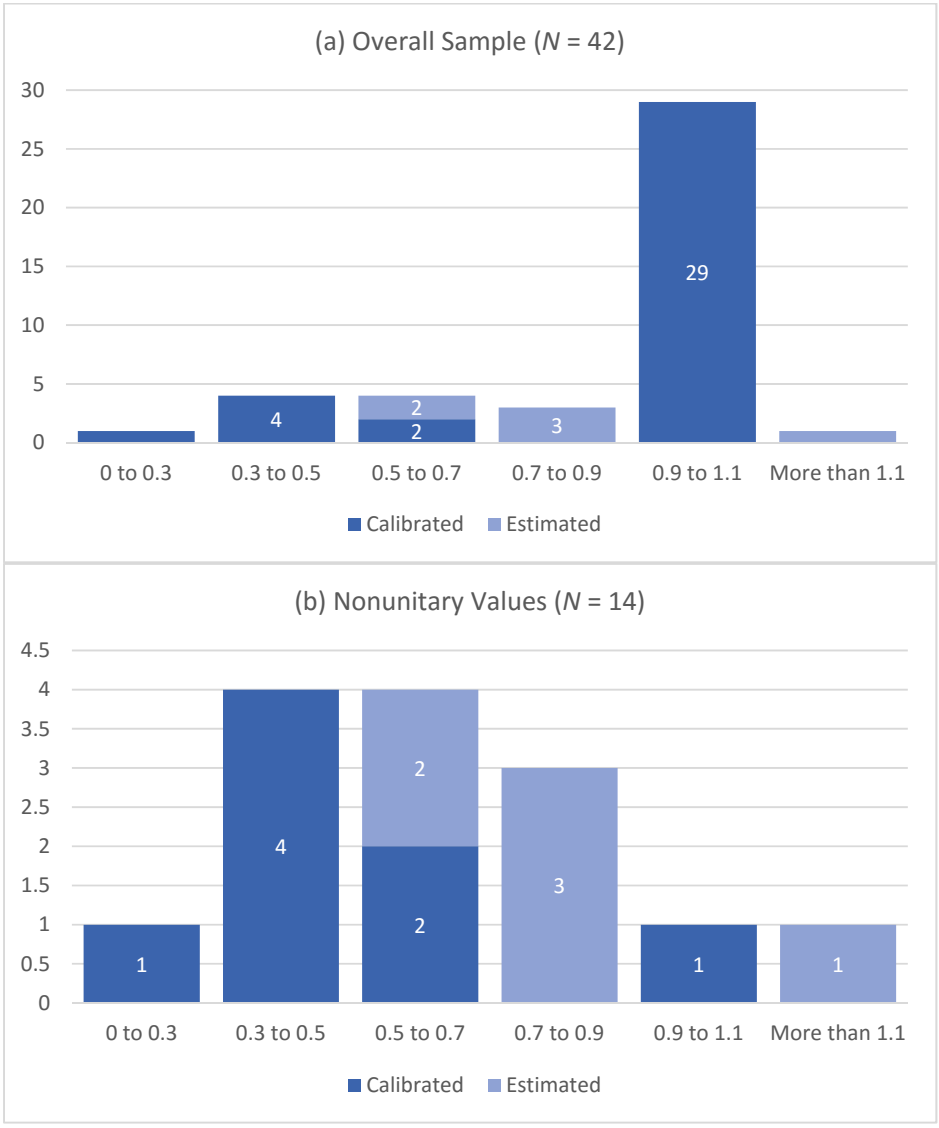

Note: The sample includes 58 policy institutions used in our baseline sample of 84 models. Multiple objectives are allowed for a given institution. For more details on the individual institutions, see Appendix Table A.2.

Figure 3: Distribution of DSGE Models by Year and Type of Institution



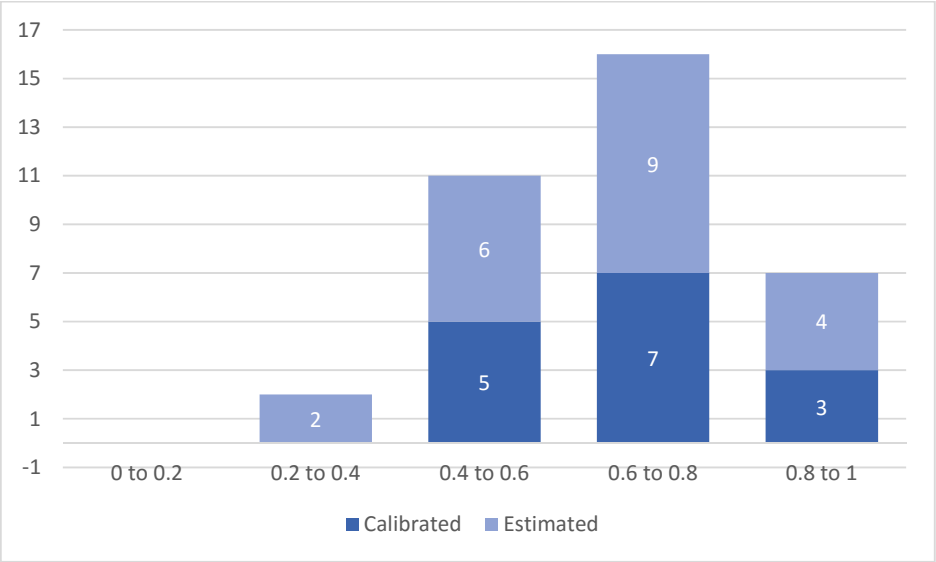

Note: The sample includes 84 models used in our baseline sample. The year is defined as the year of publication of the main reference document.

Figure 4: Distribution of the IES Parameter



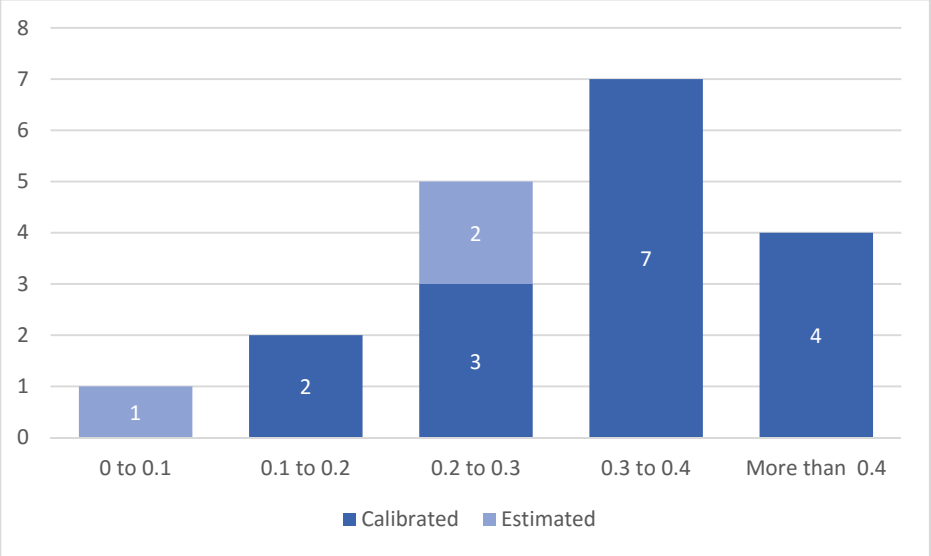

Note: The sample in panel (a) includes 42 models that are used in the model comparison exercise in Section 5 (36 calibrated, 6 estimated). The samples in panel (b) include 14 models that assign nonunitary values for IES (8 calibrated, 6 estimated).

Figure 5: Distribution of the Consumption Habit Parameter



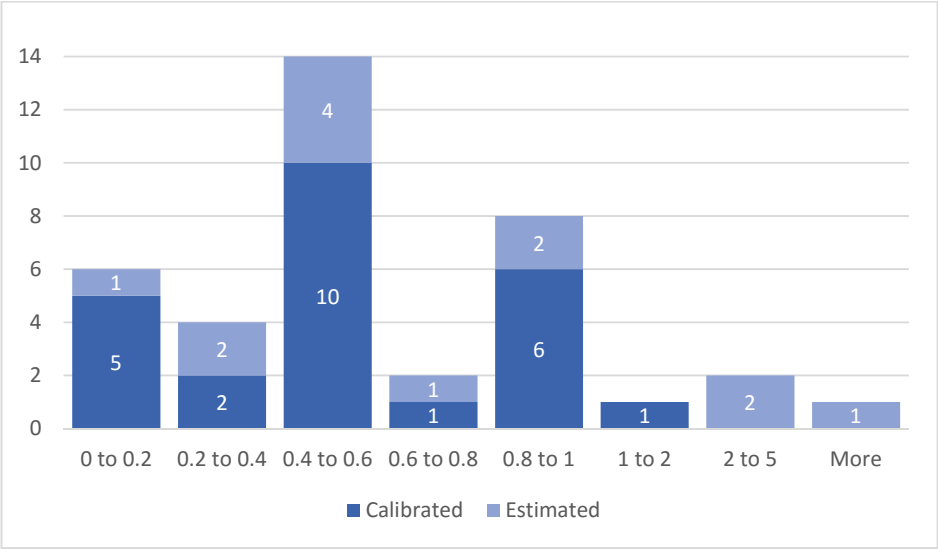

Note: The sample includes 36 models that apply non-zero habit parameter (15 calibrated, 21 estimated).

Figure 6: Distribution of the Hand-to-Mouth ("HtoM") Households Share Parameter



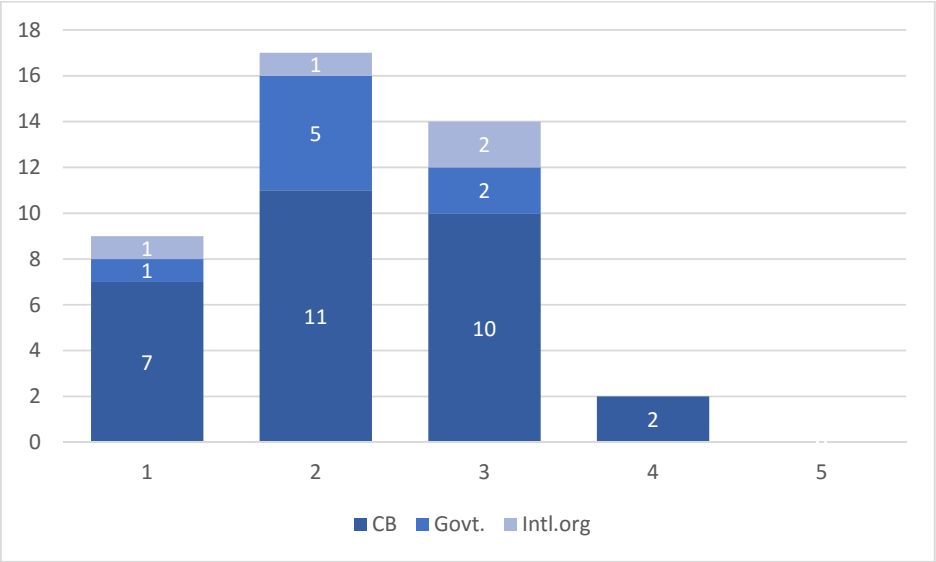

Note: The sample includes 19 models that adopt the HtoM approach (16 calibrated, 3 estimated).

Figure 7: Distribution of the Frisch Labor Supply Elasticity




Note: The sample includes 38 models that present Frisch elasticity (25 calibrated, 13 estimated).

Figure 8: Distribution of the Score Card




Note: The evaluation score is based on the following five questions with one point rewarded if the answer is yes to the following five questions: (1) Does the model adopt nonunitary value for the consumption IES? (2) Does the model allow habit formation in consumption? (3) Does the model introduce heterogeneity in households? (4) Does the model incorporate financial frictions? (5) Does the model include unemployment?