Within the Economic Machine: Evaluating the Dynamic Stochastic General Equilibrium Model

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ABSTRACT OF THE

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The Dynamic Stochastic General Equilibrium (DSGE) model is a model that is widely used in central banking today and has seen significant development in the past 20 years. However, the model still has important limitations and notable critics. This thesis provides a literature review into the history, structure and uses of the DSGE models within central banking as well as the most common criticisms made towards the DSGE framework. Understanding the DSGE model also gives significant insight into understanding general macroeconomic theory and modelling practices. The thesis finds that even though the DSGE framework has failed in predicting the biggest economic downturns, central banks can find good use cases for the model.

Keywords: Macroeconomics, DSGE, macroeconometrics, modelling, Lucas critique

Contents

1 Introduction

Forecasting business cycles is of utmost importance to economists and central banks, since the toolkit at central banks' disposal typically has no direct immediate effects and can only be observed after a time lag. Forecasting has therefore always been an important part of central banking. There is a multitude of different methods used for forecasting possible business cycle fluctuations, ranging from probit models which are standard for forecasting recessions (An et al., 2018) to more advanced statistical methods (Foerster and Choi, 2016) or machine learning (Papadimitriou et al., n.d.). A significant part of macroeconomic theory is also focused on understanding business cycle dynamics, with a lot of discussion around the topic during the last decade.

Even though economists spend a lot of effort trying to forecast business cycles and their shocks, they have not been very successful at this in the past. For example, while forecasters are typically aware that recession years will be different from other years, they typically miss the magnitude of an upcoming recession until the forecasting period draws to a close (An et al., 2018). These shortcomings are often talked about by critics, yet policy forecasters don't always change model regimes after failed predictions. (Hendry, 2020).

This creates an interesting question. How are state of the art macroeconomic models built, and what features do central bankers want to see in them? Why have these models and economists failed to predict large economic downturns, and how much of a failure on economists' part is this?

Because the topic is broad and space is limited, focus will be on the inner workings and history of the Dynamic Stochastic General Equilibrium (DSGE) model, since it is not only a commonly used model within central banking, but also a modern structural macroeconometric model. The focus of this paper is therefore to provide a literary review of the history and objectives of the DSGE model, and critically evaluate how they are used within central banks today. Understanding the assumptions behind the DSGE model will also help understand modern macroeconomic theory and what institutional forecasters value and find important.

Both DSGE models and general macroeconomic forecasting have been written of extensively. However, some of this literature, especially in regard of the usefulness of the DSGE models, is heavily divided into proponents and opponents of an argument, with no clear consensus. Therefore, it can be hard to get a clear picture of the true merits and pitfalls of the DSGE models.

Additionally, it can be challenging to tie usage of the DSGE to wider macroeconomic contexts.

The structure of the thesis is as follows: in section 2, the history of macroeconomic forecasting will be briefly explained to give context for modern DSGE models. In section 3, the DSGE model will be introduced. In section 4, the usage and forecasting performance of DSGE will be explained, along with a brief view into alternative models. There will be also discussion on DSGE forecasting within central banks. Finally, conclusions and references will be provided.

2 History of Macroeconomic Forecasting

This section will go through some key concepts and give context needed to fully understand the contents of the overall thesis. It will provide a general introduction to economic forecasting as well as a generalized history of evolution of economic forecasting. Understanding this history and especially the Lucas critique will give important insights into the design decisions behind the DSGE model. Finally the section will explain the broad economic theories, the rational expectations and the general equilibrium theory, which the DSGE model is built upon.

2.1 Introduction to Economic Forecasting

Macroeconomic forecasting is a vital process for conducting monetary policy, since both the effects of policy and the objectives of policymakers are set in the future rather than the present, and understanding the future direction of the economy is vital to making informed policy decision (Pescatori and Zaman, 2011, Wieland and Wolters, 2013). Research papers on the use of forecasting in policy go back to Theil (1958), who suggested that "policy authorities have to predict impending changes in the economic landscape" as well as predict the effects of their own policy on the economy. Authorities should also conduct policy in line with these predictions (Wieland and Wolters, 2013). Authorities therefore need models that not only predict the direction of important economic variables, such as inflation our output, but also models that give insight into what the economy could look like under alternative policies (Pescatori and Zaman, 2011).

There are a multitude of ways to conduct a macroeconomic forecast. Typically, there are three broad categories that models are divided into: structural, nonstructural and large-scale models (or semi-structural models) (Pescatori and Zaman, 2011). Next, each category will be explained on a general level while giving context behind the history of the macroeconomic modelling practice.

Structural models try to explain the economic world using structural equations, which model the expectations or utilities of economic actors and opportunity sets these actors act in. They are tightly intertwined with economic theory, which is used to create the actors and their expectations (Low and Meghir, 2017, Pescatori and Zaman, 2011). These models typically have the opportunity to model alternative policies, and they use a clear set of assumptions for the agents in the model (Low and Meghir, 2017). The tradeoff typically is that these structural models struggle to match pure statistical models in forecasting key macroeconomic variables, such as the GDP or the inflation (Pescatori and Zaman, 2011).

In addition to structural models, there are also non-structural models which are typically purely statistical time-series models. They don't use economic theory to explain the relationships in the data and are thus able to more closely match it. These models, one example of which are vector autoregression (VAR) models, are useful when the way in which the economic variables interact with one another does not change, f. ex. the monetary policy is not changed. Since this is often the case, these models are often used in multiple policy institutions. (Pescatori and Zaman, 2011)

Finally, there are semi-structural models (or large-scale models) which stand between structural and nonstructural models. Semi-structural models use economic reasoning to form their base, but relax several of the restrictions to allow for closer matching with the data as well as increase the intuitiveness of the model (Angelini et al., 2019). The relaxed economic restrictions also allow for a higher amount of variables in the model, thus diminishing the risk of omitted variable bias (OVB), which is a common pitfall of structural models (Wilms et al., 2021, Low and Meghir, 2017).

Typically, decision makers don't use only one model, and rather aggregate multiple models to create a consensus of possible projections. For policymakers, simply getting a forecast output is often not enough to suggest policy. More important than outputting a specific print is understanding how different explanatory variables and the output interact with one another. (Robertson, 2000)

2.2 Early History and the Lucas Critique

Understanding business dynamics through theory and statistical models alike has been a common topic in econometrics for decades. The first steps towards understanding the economy with models required first conceptualizing the economy as an *interacting system* and collecting time-series macroeconomic data. It was also important to distinguish economic concepts to build coherent models, such as understanding the partial as against simple correlations or formulating equations of economic systems. Modelers also needed to build necessary statistical tools in order to model the economy as one single system. Finally, it was important to find users for econometric models, such as financial institutions or central banks. (Hendry, 2020)

The thesis' analysis of the history of development of macroeconomic models starts from the second world war, which saw multiple developments in the availability of macroeconomic data, such as the construction of price indices, as well as a lot of progress in the field of econometrics. Even though models in this era were still far from perfect, they set the groundwork for future work alongside with the increase of availability of macro data as well as the increase in computational capabilities. (Hendry, 2020)

The next time big leaps in macro-econometric forecasting were taken was in the 1960s, which saw the development of the first large-scale econometric models (also referred to as semi-structural models, see chapter 2.1) (Pescatori and Zaman, 2011). These models were brought forth by the rise of popularity of Keynesian theory as well as the increase in computational power (Pescatori and Zaman, 2011), and they were built for both the US and European central banks (Hendry, 2020). The optimism and popularity for these models and Keynesian macroeconomic theory in general was however cut short by the tumultuous stagflation of the 1970s (Hendry, 2020).

Such an example of the models that lost popularity due to the stagflation is the Phillips curve, which plots the inverse correlation between inflation and unemployment. The proponents of the model suggested that by increasing inflation a policymaker could permanently lower unemployment. At the height of the popularity of the theory, Milton Friedman and Edmund Phelps challenged the notion of the trade-off, arguing that the effects of the negative correlation are only temporary, and unemployment would shift towards its natural level of unemployment. (K. Hoover, 2022)

Robert Lucas later argued that this was a wider problem with econometric and other forecasting models. In his influential paper he argues that since all parameters of traditional econometric models depend on the agents' expectation of the policy process, the models are unlikely to remain stable as policymakers change their behaviour (Rudebusch, 2002). This means that economic models using only past data or observing past relationships are unstable in face of new policies that change the way of interaction between economic agents. Thus, models should be built based on economic fundamentals, making them invariant to policy changes (Lucas, 1976).

It should be noted that a natural suggestion of the Lucas critique is that models without expectations in their parameters should make poor choices for analysing phenomena with policy shifts, such as monetary policy. However, such macroeconomic models, such as VAR models without explicit expectations appear to be quite stable empirically (Rudebusch, 2002). Semi-structural models also still remain the main forecasting method of multiple central banks, such as the ECB (Darracq Paries et al., 2021).

Nevertheless, the Lucas critique has shaped the macroeconomic modelling landscape in a multitude of ways. On one hand, central banks continued using and developing existing models since they were the only available framework, and on the other hand, academic economists strove to build new models that could satisfy the Lucas critique. This effort to build new models brought forth the first "general equilibrium" structural models, which aim to build macroeconomic models on top of so-called microeconomic foundations, and thus address the Lucas critique (Rudebusch, 2002).

One example of such models was the family of Dynamic Stochastic General Equilibrium models, which build upon rational expectations and real business-cycle theory, two concepts that we will visit in upcoming chapters. The Lucas critique is also an influential part of the development of economic thought, and thus will be revisited in this thesis when evaluating possible reasons for failures of economic forecasting.

2.3 Rational Expectations and Real Business Cycle Theory

In this section, both the Rational Expectations and the Real Business Cycle theory will be explored in greater detail to allow better understanding of the theoretical framework DSGE models are built upon. Both of the theories will be explained on a general level to give insight into the both the framework and the limitations of the DSGE models.

The rational expectations theory is simple at its heart: economic actors tend to, on average, have expectations that are more accurate than naive expectations (Muth, 1961). They also optimally use all information available to them, including information of existing and hypothetical policies, to forecast and expect the future (Mankiw, 2010).

Now, it is important to state that the rational expectations hypothesis does not expect that every economic agent expects the future correctly, but because mistakes can happen in both directions compared to a prediction, mistakes ought to be normally distributed around the correct value and thus be, on average, unbiased. (Frömmel, 2017, Muth, 1961)

The Real Business Cycle (RBC) theory can be thought of as a subcategory or a preceding framework of the New Keynesian DSGE models, which were developed to deal with the shortcomings of the RBC theory (Slanicay, 2014). There have been many distinct RBC models with differing features and assumptions, though typically RBC theory assumes perfect competition of the goods and labour markets as well as flexibility in prices and wages (Rebelo, 2005).

The concepts of RBC theory became of interest because of the assumptions above, but also the predictive power of the models and the policy implications they pose. RBC models were successful at matching some unconditional business cycle patterns, and inputting technology shocks into the model resulted in equilibrium paths that matched historical data "unexpectedly well" (Slanicay, 2014). The policy implications that interested economic modellers was that money was largely irrelevant (Hendry, 2020) and that business cycle fluctuations were mostly caused by technological shocks to the economy (Rebelo, 2005).

However, RBC models soon faced critique for assumptions such as the irrelevancy of the macroeconomic policy. Other things the models were criticized for were the overemphasis on technological shocks on business cycle fluctuations or unrealistic parameters. The New Keynesian DSGE models were developed to address these issues (Slanicay, 2014). The following chapter will go more in-depth on how the New Keynesian DSGE models work.

3 The Dynamic Stochastic General Equilibrium Model

This section will explain the structure of the DSGE models, first on a general and intuitive level, and then on a deeper and more mathematical level. It should be noted that in this section and thesis "DSGE" will refer to the New Keynesian DSGE models specifically.

3.1 Introduction to the DSGE Framework

Even within the category of the New Keynesian DSGE models, there are multiple proposed models. First there will be given a general overview of the DSGE models, which is based on the article by Sbordone et al., 2010.

DSGE models are, at their heart, relatively simple. They contain three blocks: a demand, supply and monetary policy block. These blocks interact with one another in an economy that is cleared at the end of every time step. Below is a graph to visualize the way the model is built:

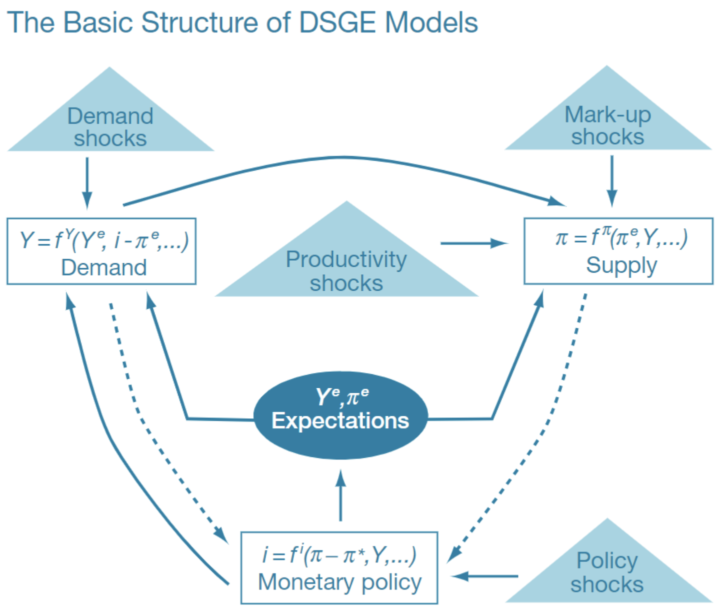

Figure 1: The Basic Structure of a DSGE Model (Sbordone et al., 2010).

As one can see, the blocks are defined by functions, which are built upon the "micro-foundations", equations denoting actions of economic agents based on their maximum expected future utility. This chapter will feature only a brief overview of each economic agent, to give more context to the upcoming chapters.

The demand block can typically be thought to represent households. They output a level of real activity (Y in the diagram), which is denoted as a function of the difference between the nominal rate and expected inflation as well as the expected future output. This has an intuitive explanation: higher real interest rates lead to a higher rate of savings since it becomes more beneficial for consumers to save rather that spend capital. In tandem, higher expected future output leads to higher spending since optimistic future expectations lead to higher spending regardless of current interest rates or inflation.

The demand block is connected to the supply block, typically representing firms producing goods, which set a general price level for the economy. Their function uses both the aggregate output from the demand block and the expected inflation level to generate an inflation (price) level for the economy. On an intuitive level, this means that higher activity levels lead to higher wages and thus higher price levels, and higher inflation expectations also lead to higher price in the present time.

The supply block and the demand block are both connected to the monetary policy block, denoting that both the inflation and the price levels of the economy denote how a central bank sets the nominal interest rate and thus sets the expectations for the market. In DSGE models, monetary policy typically affects the markets through expectations to simulate forward guidance.

One can also see that there are different shocks that affect each block. These are exogenous and stochastic shocks, which cause perturbations and fluctuations in the economy. One should note that all stochastic perturbations in typical DSGE models are exogenous, meaning that there is no uncertainty within the parameters themselves. Were it not for random outside shocks, the economy would evolve in a perfectly predictable way.

This chapter ought to give sufficient insight into the general structure of a DSGE model. In the next chapter, the mathematical formulations of the microfoundations of a specific DSGE model will be explained.

3.2 Structure of a DSGE Model

This chapter will take a closer look upon the mathematical formulations that define a specific DSGE model. For displaying the structure of a contemporary DSGE model, the model used by the Federal Reserve, the FRBNY DSGE, will be used. This model is formulated by Negro et al., 2013.

This model is a medium scale DSGE model built for one sector. As typical DSGE models do, the FRBNY is based on the neo-classical growth modelling framework, adding nominal wage and price rigidities. It also adds "variable capital utilization, costs of adjusting investment, habit formation in consumption, and credit frictions".

The model has five different economic units, which build the microeconomic foundations for the model. The units are as follows:

1. Households (Demand Block)
2. Firms (Supply Block)
   (a) Intermediate Goods Producers
   (b) Final Goods Producers
3. Financial intermediaries (Financial Block)
   (a) Banks

(b) Entrepreneurs

(c) Capital Producers

4. The Government (Monetary Authority Block)

(a) Monetary Authority

(b) Fiscal Authority

Below is a figure demonstrating the structure of the model:

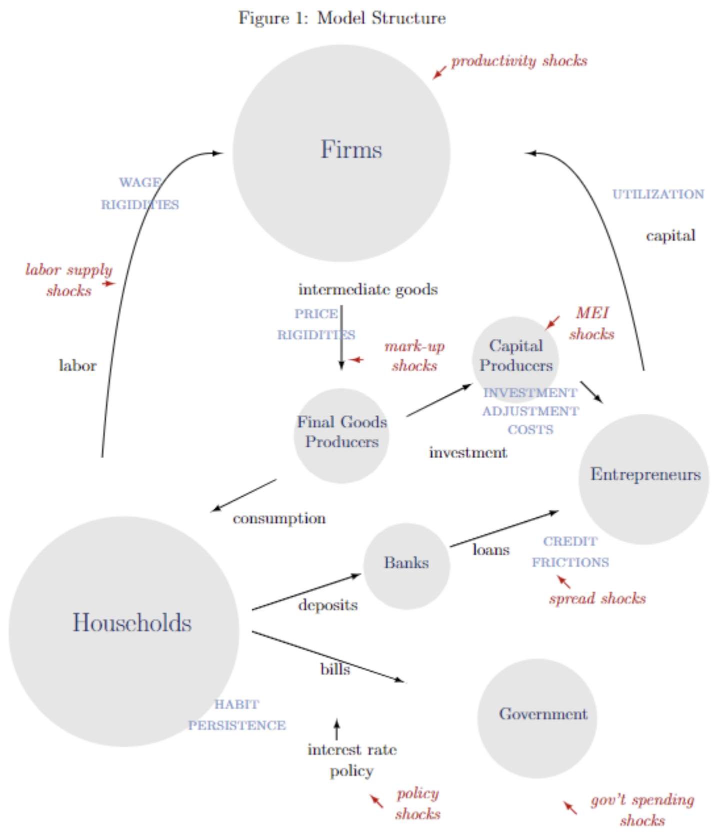

Figure 2: The Structure of a FRBNY-DSGE Model (Negro et al., 2013).

One should note that compared to the previous section, which structures a simple DSGE model as having three blocks (a demand block, a supply block and a monetary authority block), the FRBNY model has a more complex structure. The supply block is divided into two actors, intermediate and final goods producers and the FRBNY model also includes a more detailed labor market, as well as financial frictions. The frictions are represented in the form of "Financial Block", which holds in itself financial intermediaries. The inclusion of financial frictions into

DSGE modelling has been an important research topic after the 2008 Financial Crisis (Christiano et al., 2018).

1. Households

The first unit, *households*, provides firms with labour supply and has an aggregate consumption level. Their objective function is:

$$E_t \sum_{s=0}^{\infty} \beta^s \left[\log(C_{t+s}(j) - hC_{t+s-1}(j)) - \frac{\varphi_{t+s}}{1+\nu_l} L_{t+s}(j)^{1+\nu_l} + \frac{\chi}{1-\nu_m} \left(\frac{M_{t+s}(j)}{Z_{t+s}P_{t+s}} \right)^{1-\nu} \right] \quad (1)$$

Households have the following budget constraint:

$$P_{t+s}C_{t+s}(j) + B_{t+s}(j) + D_{t+s}(j) + M_{t+s}(j) \leq$$
$$R_{t+s-1}B_{t+s-1}(j) + R^d_{t+s-1}Dt + s - 1(j) + M_{t+s-1}(j) + \Pi_{t+s} + W_{t+s}L_{t+s}(j) + T_{t+s} + Tr_{t+s} \quad (2)$$

As one can see from the budget constraint and the objective function, the households choose their consumption $C_t(j)$, labour supply $L_t(j)$, total savings $M_t(j)$, holdings of government bonds $B_t(j)$ and total bank deposits $D_t(j)$, to maximize their expected utility function (1). The preferences are subject to a stochastic parameter φ, which creates exogenous supply shocks within the labour market. Households also have a certain degree of habit persistence from previous time periods, denoted here by parameter h.

Key takeaways should be that households maximize their utility knowing the values for each variable from hereon to infinity (as is customary in models built on the rational expectations theorem). Households also choose their desired consumption and labour levels to maximize their own utility under exogenous stochastic disturbance. It should also be noted that money demand $M_t(j)$ is given as a ratio to the growth of the economy $Z_t(j)$, so that "the real money demand is stationary relative to economic growth".

2. Intermediate Goods Producers

The labour of individual households is aggregated by labour aggregators ("employment agencies") and supplied to the second actor, *monopolistically competitive firms* which act as intermediate producers of goods. The intermediate producers take the aggregate labour supply L_t, and use it to give a labor demand schedule for single households.

The intermediate production function is subject to external, "total factor productivity" TFP shocks. This is then reverbrated into nominal price rigities, which together with wage rigities allow demand shocks to cause business cycle fluctuations. This creates a dynamic situation together with labor market shocks, where either shocks to markup or demand can cause business cycle fluctuations.

3. Final Goods Producers

Final goods producers work in a competitive market, where they purchase the goods off of intermediate goods producers and aggregate them to:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_{f,t}}} di \right]^{1+\lambda_{f,t}} \tag{3}$$

Now profit maximation of firms gives an implied demand for the aggregate goods:

$$Y_t(i) = Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\frac{1+\lambda_{f,t}}{\lambda_{f,t}}} \tag{4}$$

This means that as in equation (4), the final demand for goods is defined as a fraction of this good's price from the aggregate price. These goods are then sold back to households based on their total consumption level. Since final goods producers set the aggregate price level, they also control inflation, which evolves as a function of inflation expectations, marginal costs and demand and supply shocks.

Final goods producers also sell output to capital producers, which then transform the general output into new capital.

4. Financial Intermediaries

In addition to households and firms, there are also *capital producers* in the model, firms that purchase general output from final goods producers, and use that to generate new capital which they then sell back to the entrepreneurs at the end of the period. This new capital is denoted as x' in the following formula:

$$x' = x + \mu_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t \tag{5}$$

The variable x denotes a capital borrowed from entrepreneurs and I_t is the output bought from the final goods producers. S is the cost of adjusting investment. The equation denotes that the lower the costs of adjusting investments are, and the higher the investments and loans are, the more capital gets produced. There are also exogenous changes μ_t in the model, that in case of positive shocks lead fewer resources being needed to build new capital or vice versa.

There are also *banks* and *entrepreneurs* in the model, which should be interpreted as intermediaries for modelling imperfections in the financial markets rather than what their names literally mean. In this model, entrepreneurs should perhaps be thought of as high net-worth individuals. They use their both own wealth and loans from banks, which gather deposits from households, to rent money to intermediate goods producers and capital goods producers.

Entrepreneurs manage their funds in idiosyncratic ways, and are not immune to defaulting if they cannot pay their debts in time. Banks protect themselves from entrepreneurs' defaults by both pooling the loans and charging them a spread, which can vary according to the overall risk level of the loan market.

5. The Government

Finally, there is also a *monetary authority* that sets short-term interest rates and creates policy expectations for agents. There is also a *fiscal authority* that sets public spending and collects taxes. Here the monetary authority sets an interest rate responding to possible inflation or output deviations from a set target, as a real central banking authority would. The model also features forward guidance in the form of anticipated policy shocks, which do not yet affect agents but are known to them.

The model features anticipated policy shocks in the central bank model to model the effects of forward guidance. The fiscal authority has a fully Ricardian policy so that the timing of the taxes does not sway the final equilibrium. In the model, government spending follows an exogenous process and features demand shocks.

This section gave insight into how a state of the art DSGE model is built and how some microfoundations within it are characterized. The next section will delve into what results the DSGE has yielded.

4 DSGE Model in Macroeconomic Forecasting

In this section the results and implications of the DSGE model will be gone into in greater detail, as well as possible explanations for failures of the model. These results will be tied into a larger context of macroeconomic forecasting and possible shortcomings of general models in business cycle forecasting.

4.1 Forecasting Results and Implications

The forecasting accuracy of economists in general has been widely studied in literature. Typically the proponents of a model validate the robustness of their model using historical data ("backtesting"), and there is also general research done to compare models with one another. Typically many forecasters use a benchmark to compare their findings to, such as the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF) in the case of the FRBNY DSGE Model (Negro et al., 2013) or the Federal Reserve Board's staff judgemental projections for FOMC meetings (the "Greenbook") (Edge et al., 2009).

There is also extensive research on the forecasting performance and general robustness of DSGE models, with varying results. In general, there is a sense of progression in using DSGE models for forecasting. Pagan (2003) classified the DSGE model as theoretical rather than empirical, and stated that "the models are approaching a size and complexity where they might actually be used in policy analysis".

Typically structural models are thought to sacrifice forecasting power to add economic theory. However, only four years after Pagan's (2003) paper, DSGE models achieved the same empirical forecasting results as VAR or BVAR models with added theoretical rigour (Smets and Wouters, 2007). This paper in particular has lead to much empirical work using DSGE models for study the business cycle dynamics in numerous countries (Marcellino and Rychalovska, 2014).

In the FRBNY DSGE Model that was covered in detail in section 3, Negro et al. (2013) also found that their model yielded similar if not better performance than the median SPF forecasts. They found that the benchmark had a tendency to be overly optimistic of recovery since financial crises, a feature that model was conversely slightly too pessimistic of. From these findings one can see that a positive trait of the DSGE model is its transparency (Christiano et al., 2018), in that the builder of the model can accurately observe what the model missed and how it formulated its forecasts.

The success of Smets (2007) also led to other modellers testing the forecasting performance of DSGE models. Adolfson, Lindé and Villani (2007) also achieved competitive results with DSGE models when comparing to reduced form models such as VAR models. They also found out that applying restrictions implied by DSGE models to VAR models could also improve the out-of-sample forecasting capabilities of VAR models. Marcellino and Rychalovska (2014) also found that the DSGE model produced significant forecasting improvements over unrestrained VAR models, with longer forecasting horizons.

In addition, Edge, Kiley and Laforte (2009) found that DSGE model outperformed the Greenbook projections, which they concluded was a significant result since the Fed devotes significant resources to performing these projections (Edge et al., 2009), they are generally thought to be of a very high quality (Romer et al., 2002), (Sims, 2002) and they play a significant role in defining policy (Romer et al., 2002)

It should be stated that simply evaluating out-of-sample forecasting performance is not a good evaluation metric for the theoretical robustness of a model unless that model is built to simply conduct forecasts (Clements and Hendryà, 2005). This is the case especially for the DSGE, which is built to model the economy under alternative policies (Christiano et al., 2018). Therefore, good or poor out-of-sample performance ought not to be a sign of either validation or invalidation for a model.

Even though multiple DSGE modelers and researchers gave good results for out-of-sample performances of DSGE models, it should be noted that these models failed to predict both the 2008 financial crisis and the Great Recession (Christiano et al., 2018). This is a common property for all economic forecasts, which typically miss the emergence of recessions as well as the declines of output during the recessions (An et al., 2018). This issue affects both private and public sector forecasts, and there are multiple theories over why this could be the case for DSGE specifically. The thesis will go into greater detail over possible reasons for failures in the next section.

4.2 Criticisms

In this section possible criticisms of the DSGE model and macroeconometric forecasting in general will be explored. Even though the DSGE model is widely used, there are notable critics of the model. The criticisms are typically directed towards one of the following features of the DSGE framework:

- Rational expectations theory and the use of microfoundations
- Lack of heterogenous agents
- The failures of forecasting major economic downturns

Perhaps the most widely known DSGE critic, Stiglitz (2017) heavily criticises the DSGE model, arguing that the DSGE model fails in the necessary functions that a macroeconomic model should be able to perform. The author argues that the microfoundations behind the DSGE model are fundamentally flawed and do not reflect real economic actors. Behind the flawed microfoundations are not simple simplifications but wrong modelling choices altogether.

In a DSGE model, downturns are caused by exogenous technology shocks (Negro et al., 2013). Stiglitz (2017) questions the existence of such an event in a modern industrialist society, also arguing most economic shocks are endogenous in nature, such as the 2008 housing crisis. Stiglitz argues that by making shocks strictly exogenic the model fails to detect the increasing vulnerability of the economy itself. Stiglitz also claims there are numerous other things wrong with the DSGE model, such as the lack of financial frictions, lack of addressing of nonlinearities and lack of ability to provide policy advice, poor econometric method and the lack of heterogenous agents.

Christiano, Eichenbaum and Trabandt (2018) wrote a response to criticism towards the DSGE model, with specific arguments to address Stiglitz's claims. The authors debunk multiple claims made by Stiglitz as incorrect, such as that the models would be estimated using Hodrick-Prescott filtered data to detrend the time series. Other debunked claims include claims regarding the lack of existence of financial frictions (several counterexamples are provided) or the lack of addressing of nonlinearities.

According to Christiano, Eichenbaum and Trabandt (2018), the reason for not being able to forecast the financial crisis was due to the inability to model the vulnerability of the US economy to a financial crisis. They argue that this reflects the larger economic community, which was not able to foresee the way the US housing market had evolved. Since the financial crisis there have been developed models that can simulate financial crises and financial frictions (Benes et al., 2014).

There has also been other criticism over using the rational expectations representative agent models as unrealistic. Colander et al. (2008) argue that microfoundations are at their core a choice variable of economists, and they should be replaced with some empirically generated variables.

A case that was raised in both the criticisms of Stiglitz (2017) and Colander et al. (2008), and one that Christiano, Eichenbaum and Trabandt (2018) could not outright debunk, was a criticism of a lack of heterogenous agents in one model. Colander et al. (2008) argue that with contemporary computational methods it is possible to start developing new, more realistic models, which feature heterogenous agents, endogenous learning and multiple equilibria. They suggest Agent Based Computational models to address these issues. These models will be explored in greater detail in chapter 4.3.

Even though DSGE models were developed to address the Lucas critique (Boumans and Duarte, 2019), Sergi (2018) states that there is substantial evidence that parameters in DSGE models are not stable between policy regimes, and thus the model fails at addressing the Lucas critique. One such example is the empirical research conducted by Hurtado (2014), states that policy changes cause drift in multiple parameters, including ones which are supposed to be structural (such as habits of elasticity). Moreover, Hurtado (2014) finds very similar behaviour when comparing the DSGE model to a standard old-style Phillips curve.

Storm (2021) however states that macroeconomic models do not need to pass the Lucas critique. They argue that impacts of policy changes on parameters are typically negligent and thus the Lucas critique is not necessary for macroeconomic models. Storm (2021) also criticises DSGE models and macroeconomic modelling in general for a multitude of reasons, such as the belief that macro-models need microfoundations, rational expectations or the trade-off between consumption in the present or the future.

According to An et al (2018), there are also general problems with economic forecasting, which include but are not limited to:

1. Insufficient information to reliable forecast the future states of an economy
2. Greater loss for forecasters for incorrectly calling a recession or correctly calling one
3. Behavioural reasons to hold on to one's prior and only slowly accept new information sources

These are also possible reasons for failures of forecasting using DSGE models.

Storm (2021) and other critics often propose alternative models to the DSGE model. In the next section, the alternative models proposed by critics will be explored on a general level.

4.3 Alternative Models

There are multiple approaches alternative models take. Some try to stray away from microfoundations or general equilibrium rules, or increase the role of empirical modelling as opposed to theoretical. This chapter will highlight some of the models proposed by critics, specifically the agent-based computational economic models, dynamic disequilibrium theory and empirically focused macroeconometric models.

Agent-based computational economic (ACE) models economic systems as groups of autonomous interacting agents. In ACE models, the modellers build a environment where agents can interact with one another, and then fill it with both economic agents and representative agents. Examples of other representative agents include the government, some other societal intermediary or even environmental phenomena, such as the weather. These agents then interact repeatedly and dynamically learn from each other, using modern computational techniques such as reinforcement learning or genetic algorithms. (Tesfatsion, 2002)

Colander et al. (2008) however note that ACE models are currently too simplistic to use for policy, and would require making the modeling results available to the model itself, thus making the model endogenous in regard with its own modelling process. Since sidestepping this problem with rational expectations would make building an alternative model irrelevant, ACE models still have major hurdles to clear.

Heterogenic actors are also implemented by Guzman and Stiglitz (2020) propose an alternative way of approaching macroeconometric modelling, which gives away with rational expecations or general equilibriums. They call this framework a "Dynamic Disequlibrium Theory with Randomness". In this theory, the economy is modeled as a continually evolving random process with individual heterogeneity in agents. Guzman and Stiglitz (2020) believe that their framework gives a more coherent understanding of both endogenous risks in economic actors and general economic development. (Guzman and Stiglitz, 2020)

In the realm of more empirically-focused macroeconometric modelling there exists an alternative modelling approach proposed by Hoover et al. (2007) , which the authors propose as an alternative to DSGE models. They essentially suggest that instead of creating *a priori* microeconomic foundations, one should first empirically estimate how different actors interact, and then build theoretic frameworks upon these estimations. This way of formulating theory would be more akin to physics or other classical sciences.

It should be noted that these alternative approaches still ought to address the Lucas critique. These empirical estimations should be good enough at capturing human interactions that they are impervious to future policy or economic changes. Many of them are also very new models or framework, with not a lot of literature or research done on them, which ought to be also kept in mind.

This section has gone through the results, criticisms and alternatives for the DSGE models on a broad level. The next section will show how the DSGE is currently used in policymaking.

5 Applications for Policymaking

DSGE is widely used in policymaking, with many central banks having their own DSGE models to assist their decision-making. This section will contain a general overview of usage of DSGE models in central banking, as well as an overview on what methods and model characteristics central bankers and other policymakers value and how DSGE could respond to these concerns.

5.1 DSGE in Policymaking

This section will go through how the DSGE is used in different policy institutions, starting with the Federal Reserve.

There, the DSGE model is used to guide the discussions of the Federal Open Market Committee (FOMC). The FOMC, held eight times a year, "reviews economic and financial conditions, determines the appropriate stance of monetary policy, and assesses the risks to its long-run goals of price stability and sustainable economic growth" (“The Fed - Federal Open Market Committee”, n.d.). Before these meetings, all participants are given a "Tealbook", which has two distinct parts: Part A contains a summary and analysis of recent economic developments in the United States and the rest of the world, and part B contains specific policy options for the committee to consider (“The Fed - Federal Open Market Committee”, n.d.).

The first part of the Tealbook contains forecasting of alternative economic scenarious as well as general economic analysis. These alternative scenarios include sensitivity analysis to currency or commodity value changes, and DSGE is one model used to conduct such analysis. The part also contains possible future outcomes where the Fed pursued alternative monetary policy as well as model-based estimates of optimal policy rules. The DSGE model is an integral, yet not exclusive, part of conducting these forecasts. The DSGE is also used among other models in part B of the Tealbook to generate quantitative insights of results of the possible policy options. (Christiano et al., 2018)

In addition to the Federal Reserve, the DSGE is also used by the European Central Bank, the International Monetary Fund and multiple national central banks such as the Sveriges Riksbank, the Czech National Bank and the Bank of Canada (Christiano et al., 2018) as well as the Bank of Finland (Darracq Paries et al., 2021).The ECB uses two complementary estimated DSGE models: The New Area Wide Model (NAWM) and the Christiano, Motto and Rostagno (CMR) Model. These models act as complements to each other and both support the policy making process of the ECB (Smets et al., 2010).

In the ECB, macroeconomic models are used in a variety of areas. One important area is the preparation of macroeconomic projections for the Eurosystem, which is largely model-based. Here models are used to build alternative scenarios, conduct sensitivity analysis and produce quantitative insights into possible policy choices (Darracq Paries et al., 2021). Models also help forecasters develop an economic understanding of underlying macroeconomic trends. The ECB uses DSGE models to complement their main macroeconomic projection tools, which are semi-structural macroeconomic models (Darracq Paries et al., 2021).

Structural models still provide support for the daily analytical work of the ECB, and the new advances in DSGE models form a vital part of the policy research agenda. Within the European System of Central Banks, the Central Bank of Sweden (Sveriges Riksbank) and the Czech National Bank (Česká národní banka) are brought up by both Darracq et al. (2021) and Christiano et al. (2018). Both have adopted a DSGE model complemented by other tools for the core of their forecasting tool portfolio and also, to some extent, for their policy analysis (Darracq Paries et al., 2021).

Central Bank of Sweden uses a two-economy DSGE model (called "MAJA") due to importance of foreign trading partners to Sweden's economy, equipped with global shocks to model the foreign drivers of Swedish GDP and the repo rate more accurately than the Bank's previous models (Corbo and Strid, 2020). In addition to MAJA, the Central Bank of Sweden also uses other DSGE models in policy analysis (Darracq Paries et al., 2021).

The Bank of England is also developing DSGE models for policy purposes and forecasting. Even though Sims (2002) wrote that DSGE models did not achieve good enough results to use them for forecasting, Burgess et al. (2013) wrote eleven years later that the BoEs COMPASS model achieves satisfactory results and is used for forecasting. However, within the Bank there are economists who do not seem to believe that DSGE models are able to match data closely enough, and suggest using models that utilize empirical evidence rather than economic theory (Hendry and Muellbauer, 2018).

The Czech National Bank uses their newly-developed DSGE Model ("g3+") as a core model. This too, is a two-economy model with a domestic and foreign market, represented by the "effective euro area", and important improvement points are the ability to let forecasters implement their judgements into the model's framework to provide the modellers and their audiences with a more cohesive experience. It also features new concepts compared to previous model ("g3"), such as the ability to model imperfect information for decision makers. (Brázdik et al., 2020)

The Bank of Finland also uses a open-economy DSGE model, the Aino model. The Aino 3.0 model, the most contemporary one, is a small open-economy model used within the Bank of Finland for policy analysis. It models Finland as a small member of a monetary union, and aims to capture domestic Finnish problems such as high indebtedness of households and a volatile construction market. (Silvo and Verona, 2020)

The International Monetary Fund (IMF) also uses multiple DSGE models in their bottom-up analytical process, where first country-wide teams generate country-specific analyses, which are then aggregated into one international model by the World Economic Outlook (WOE) team. Models featuring DSGE frameworks include the Global Projection Model (GPM), which assists country desks to perform their WOE forecasts (Darracq Paries et al., 2021, Carabenciov et al., 2013).

Other examples include the Global Economic Model (GEM) (Pesenti, 2008) or the Global Integrated Monetary and Fiscal Model (GIFM) (Kumhof et al., 2010) as well as the Global Fiscal Model (GFM) (Botman et al., 2007). The models again complement one another, with the GEM being able to create believable short-run dynamic and the GFM being able to model longer-term dynamics of different fiscal policies, an area where the GEM fails (Botman et al., 2007).

Below is a table featuring DSGE models used by different policymakers.

DSGE Models in the eurosystem and outside of it:			
Name	Projections	Other Policy Use	References
CZ	G3+	G3+	Brázdik et al., 2020
SE	MAJA	MAJA	Darracq Paries et al., 2021
US	EDO, FRBNY	EDO, FRBNY	Christiano et al., 2018
UK	COMPASS	COMPASS	Burgess et al., 2013
CA	ToTEM	ToTEM	Corrigan et al., 2021
IMF		GEM, GIFM, IPF	Botman et al., 2007
EC	QUEST III, GM	QUEST III, GM	Ratto et al., n.d.
FI	Aino 3.0	Aino 3.0	Silvo and Verona, 2020

5.2 Why the DSGE?

It is clear that multiple policymakers value the DSGE and want to incorporate it into their macroeconomic projections and modeling. In this chapter, details will be presented over what policymakers value in macroeconomic models and how the DSGE provides these things.

It is clear that central banks need forecasts to achieve their goals, since there is significant variable lag in the monetary transmission mechanisms and thus central banks cannot directly change current inflation or total output. It is believed that central banks should set their objectives on a medium time horizon for conducting policy (Weber, 2009). Forecasts are also useful for setting expectations for firms and households and thus making the central monetary authority more effective at fulfilling their goals (Weber, 2009).

A good forecast for a central bank authority has a few important characteristics, such as transparency. The ability to build a good economic rationale behind a model is needed so that a policymaker can educate the markets on their idea of the economic dynamics that are believed to exist behind a policy decision (Wieland and Wolters, 2013). Thus, decision makers ought to start from simple models that they can meaningfully project their views onto rather than try to build an all-comprehensive model from the get go. The possibility to be able to embed the policy views of the decision makers is of great importance as well (Laxton et al., 2009)

The strength of the DSGE Model is that it delivers an internally consistent and transparent result that can easily be reverse engineered and explained through modern macroeconomic theory. Policymakers can embed their inflation expectations in the model to build long-term projections, and on the other hand real-time information can also be built in the model (Negro et al., 2012). The models are easy to explain and build a story around, modular since they are representative-agent-models and ever-growing since a lot of research in the field is done constantly (Christoffel et al., 2010, Christiano et al., 2018). There is a lot of exciting work done in regard of development of new DSGE models incorporating things such as heterogenous agents, social learning or other deviations from the classical theories of rational expectations (Christiano et al., 2018).

Will the new, improved, DSGE models be able to predict the next economic crisis? Probably not, since there is not a fool-proof way to foresee the future. However, every single economic crisis has left its mark on how DSGE models are built.

Ultimately, forecasters do not value only the models that yield the most accurate univariate forecasts for a single variable. DSGE models are a good overall package that produces forecasts that are accurate enough, allow researchers to built meaningful narratives around modelling results and allow for structural shocks. Even models that can do all of these things, such as dynamic factor models, typically don't allow for very complicated policy experiments nor do any widely used models allow users to gain quantitative insights into the degree of effect monetary policy can have on correcting economic distortions. (Negro and Schorfheide, 2013)

The DSGE has a lot of functionalities simultaneously. It can develop multi-variate points density forecasts that reflect uncertainty of the economy. It also provides policymakers with a device for understanding the current state of the economy through modern macroeconomic theory, as well as providing decompositions for economic shocks. Finally, the model allows users to test the effects of alternative policy scenarios (Negro and Schorfheide, 2013). As Negro et al. (2013) wrote, "while a successful decathlete may not be the fastest runner or the best discus thrower, he certainly is a well-rounded athlete."

6 Conclusions

The main result of the thesis is that the DSGE model is one of the best all-rounder models that are available for policymakers today. While certainly not perfect, it is enough of a complete tool to be useful to policymakers. The issues that the DSGE model is criticized for are issues that plague the world of macroeconometric theory in general: the idea of microfoundations and how they hold empirically, the inability to forecast large, self-propagating macroeconomic shocks and the lack of heterogenous agents. Thus looking into the DSGE models helps us to understand what are some of the key issues in macroeconometric forecasting.

A lot of work is done to work on these issues, both in the DSGE world and outside of it. It remains to be seen whether the future core models are DSGE models or some other econometric models, such as Agent Based Computational Models or some other empirical models. Probably all of them will be considered, since policymakers often use multiple complementary models to augment their decision making process.

The thesis also sheds light on how policymakers use econometric models and what they value in them. Typically, models are not used in a vacuum, but to enhance human decision making and provide talking points for policy discussion. Thus, not only the predictive power is important in the models, but their overall understandability, transparency and narrative coherence. This is also what central banks and other monetary authorities want to develop in future models:

they want to bring these models closer to the actual economy and model different economic phenomena, such as climate change or long-term trends (Darracq Paries et al., 2021). This is the main development criteria for new models and the criteria what models are evaluated on: the ability to understand how the economy actually works.

This thesis has answered a lot of questions on general macroeconomic forecasting and how the DSGE model responds to the needs of policymakers, but there are still some open questions. Even though this analysis identifies key questions and criticisms in macroeconometric forecasting, these could be still expanded. Multiple subjects only touched in this thesis could warrant their own theses, such as the validity of the Lucas Critique or the validity of the new proposed models.

This thesis also does not cover in detail the how the dynamics between DSGE models and other models are played out in public policy forecasting, and what kinds of future developments are possible for the entire central banking modeling portfolio. Other interesting questions omitted in this thesis are also the role of human decision-making at different policy institutions and how different forecasting regimes fare compared to one another.

Perhaps the most important unanswered question is: what does the next generation of macroeconometric modelling actually look like and how will it be achieved? Even though the economic community seems to agree on straying further from the rigitidies of the current models, there is no clear consensus on what the next generation of macroeconometric modelling will look like (Christiano et al., 2018). However, one can assume that things found important in today's DSGE models will be found in the future. Regardless of what the future will look like, the influence that the DSGE models have left in macroeconomic forecasting is undeniable.

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