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Behavioral Macroeconomics and an application of a behavioral model on countries of Greece, Ireland, Italy and Spain

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Abstract

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by Gagik GRIGORYAN

Recent advancements in the field macroeconomics and behavioral economics have developed new insights on how to approach problems. Old assumptions are being slowly replaced by new behavioral assumptions. This dissertation reviews the literature and estimates a behavioral macroeconomic model for Greece, Ireland, Italy, and Spain.

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Chapter 1

Introduction

Over the last two decades, more and more macro-economists implement behavioral assumptions into the macroeconomic models. According to Holden (2012) there are two main reasons for this change. First, an increasing body of research by cognitive psychologists and experimental economists has documented a number of systematic deviations in the thinking and decision-making of human beings compared to the traditional "economic man" assumptions. Thus, incorporating such features in economic models can no longer be criticized for being ad hoc. Secondly, it has become clear that standard economic models based on assumptions of optimizing behavior in many cases have problems with accounting for key real world observations. Hence behavioral assumptions have been included with the aim of making the model or theory better conform with the data.

According to De Grauwe (2012) the financial and economic upheavals following the crash in the US sub-prime market have led many to believe that macroeconomics should take into account departures from rationality , in particular departures from the assumption of rational expectations. It is possible to show that individuals have cognitive limitations, and thus are not capable of understanding the full complexity of the world and thus develop models based on a different notion of rationality.

Of course, incorporating behavioral assumptions into macroeconomic models is not without problems. Driscoll and Holden (2014) state that it is often difficult to know which features are most relevant for macroeconomic models even if there is considerable microeconomic evidence from cognitive psychology or experimental economics for certain behavioral features.

The main focus of this dissertation is to present the New Keynesian model with behavioral assumption as it was suggested by De Grauwe (2012), and later try to apply the model on the countries of Greece, Ireland, Italy and Spain. The rest of the dissertation is structured as follows: Chapter 2 presents a brief summary of the literature and the studies that have been conducted on the field of behavioral economics and behavioral macroeconomics. Chapter 3 introduces the New Keynesian model under behavioral assumptions. Chapter 4 discusses the methods of extracting and analyzing the data before using them in the model. Chapter 5 is the empirical analysis of the model and the results of the calibration on the countries mentioned previously. Finally, Chapter 7 concludes.

Chapter 2

Literature Review

2.1 Behavioral Economics

According to Mullainathan and Thaler (2000) behavioral economics is the combination of psychology and economics that investigates what happens in markets in which some of the agents display human limitations and complications. Camerer and Loewenstein (2004) state that the roots of the behavioral economics date back to the classical period, when economics were closely related to psychology. Adam Smith, who wrote the famous classical works "The Wealth of Nations" and "The Theory of Moral Sentiments", presents in the latter work psychological principles of individual behavior that are arguably as profound as his economic observations.

One of the key studies that have been conducted in the field of behavioral economics is Prospect Theory by Kahneman and Tversky (1979). In their paper they did a critique on the expected utility theory and its application on decision making under risk and they suggested a different model. They analyzed how people make choices under uncertainty and these choices are evaluated using certain heuristics. Later, Kahneman and Tversky (1992) developed a new version of the prospect theory, the cumulative prospect theory, where they add a new representation of the expected utility function, the rank-dependent or the cumulative functional, that transforms cumulative rather than individual probabilities.

Another area where behavioral economics focuses is temporal discounting. According to Doyle (2013) people are constantly making decisions that involve whether they take gains (also losses) now or at some later time(s). Economists call this time preference. There are many models that to incorporate the time preferences like the exponential discounting and hyperbolic discounting models.

Behavioral economics have also been used in other fields such as finance, game theory, and macroeconomics which we will focus on this paper.

2.2 Behavioral Macroeconomics

Behavioral macroeconomics is a relatively new topic in economics and one of the first works that discusses it is the paper "Behavioral Macroeconomics and Macroeconomic Behavior" written by the Nobel prize winner in economics George Akerlof (2002). On his work, he discusses the issues of the classical macroeconomic theory and describes how behavioral macroeconomics have produced models that comfortably account for each of these macroeconomic phenomena. One of the problems that Akerlof (2002) analyzes in his paper is the existence of asymmetric information. In some markets the presence of asymmetric information can be solved easily, while in others not and can cause serious market breakdowns. Another problem is the existence of involuntary unemployment and how New Classical economics view this as a logical impossibility. In addition, he presents another view of the New Classical economics, which is the ineffectiveness of the monetary policy on output and employment when the changes are perfectly foreseeable. He also discusses about the Phillips curve and the NAIRU and how economists back in the 1960's accepted so quickly the natural rate hypothesis, when there were theoretical and empirical evidence against it. Another issue is under-saving. We already know that usually most people save too little. The New Classical economics view under-saving and over-saving as an impossibility as well. Finally, he talks about the asset markets and income distribution. Akerlof (2002) argues that behavioral macroeconomics has shed light on all these issues and have provided the tools necessary to explain some of these phenomena.

De Grauwe (2012) tried to introduce a behavioral macroeconomic model, which we are going to analyze in the following chapters, where he uses the New Keynesian macroeconomic model and instead of rational expectations he uses behavioral assumptions. In his work, he discuses the importance of animal spirits and the effects they can have on the economy under various circumstances. Depending on the type of shock (i.e. shock on the demand side or shock on the supply side) it can have different effect on output and animal spirits. The type of policy can also influence the volatility in the economy. For example, like in the new Keynesian models, the target policy of the central bank will have a trade off effect. If the central banks focus on stabilizing the inflation, then it will result in output variability and if they focus on output stability, then it will cause inflation variability.

A bit different approach and attempt to link behavioral macroeconomics with the New Keynesian model was done by Menz (2008). In his paper, he tries to clarify the role of the time horizon, the role of the money, and the explicit modeling of capital accumulation in the model. Both finite and infinite time horizon can be useful and the differences between them are not huge. As in the neoclassical real analysis, in the New Keynesian models the money is only a veil without relevance for the economic processes. Furthermore, the paper attempts to bring together the New Keynesian Model and behavioral macroeconomics, by choosing the example of hyperbolic discounting of consumers and firms. It is suggested that this method seems promising and further research and studies need to be conducted on that field.

Driscoll and Holden (2014) also support the need to incorporate behavioral economics into macroeconomic models. In their paper they do a brief summary of the New Keynesian model and note some of its key empirical failings. One of the those problems is the lack of inertia, since shocks have immediate effects which cause them to dissipate fast. A second issue, which was also pointed by Ball (1994) and Mankiw (2001), is that the aggregate supply schedule implies that inflation is expected to fall rapidly, when the output gap is positive and the inflation in period t is greater than the expected inflation in period $t+1$. The empirical evidence show that inflation increases when the output gap is high enough.

Moreover, according to Driscoll and Holden (2014) one of the areas where behavioral economics has had the greatest impact is in the study of consumption by households. The permanent income hypothesis states that consumption should be a purely forward-looking variable, depending on the net wealth of the consumer, including expected future labor income. However, evidence show that consumption is less susceptible to news and it exhibits "excess smoothness" (Campbell and Deaton, 1989). Consumption also exhibits "excess sensitivity" and these results are shown by experimental evidence presented by Duffy (2012). They also state that behavioral assumptions can be used in the modeling of aggregate supply with focus on labor markets and on the potential role of multiple equilibria, news, and asset bubbles.

De Grauwe and Macchiarelli (2015) tried to extend the behavioral macroeconomic model proposed by De Grauwe (2012) by adding credit cycles. They assume that agents do not understand the complexity of the world in which they live, thus there is a need to introduce a banking sector in models that recognize the cognitive limitations of agents. The result they get is that the existence of banks intensifies the movements of animal spirits (endogenous and self-fulfilling movements of optimism and pessimism), creating a greater scope for booms and busts. Therefore, the banks do not create animal spirits, but they amplify them. They also found that central bank has an important responsibility for stabilizing output. The output stabilization is a tool to tame the animal spirits and improve the trade-off between inflation and output volatility.

Chapter 3

Methodology

3.1 The Model

The model that we are going to use is the one introduced by De Grauwe (2012) and it is a behavioral macroeconomic model, that follows the structure of the New Keynesian model and it consists of an aggregate demand equation, an aggregate supply equation and a Taylor rule.

Following his approach, the aggregate demand equation is given by:

$$y_t = \alpha_1 \tilde{E}_t y_{t+1} + (1-\alpha_1) y_{t-1} + \alpha_2 (r_t - \tilde{E}_t \pi_{t+1}) + \epsilon_t \tag{3.1}$$

where y_t is the output gap in period t, r_t is the nominal interest rate, π_t is the rate of inflation, and ϵ_t is a white noise disturbance term. $\tilde{E}_t$ is the expectations operator, however they are not formed rationally. Agents will choose to spend more (less) on goods and services in the current period, if the expect an increase (decrease) on their future income and/or an decrease (increase) in the real interest rates.

The aggregate supply equation is derived from profit maximization of individual producers. For analytical derivation of these three equations, please refer to the appendix. It is assumed that producers cannot adjust their prices instantaneously, but they have to wait to adjust their prices, for institutional reasons. Thus, the aggregate supply equation can be derived as:

$$\pi_t = b_1 \tilde{E}_t \pi_{t+1} + (1-b_1)\pi_{t-1} + b_2 y_t + \eta_t \tag{3.2}$$

Finally, the behavior of the central bank is described by the Taylor rule, which is given by:

$$r_t = c_1(\pi_t - \pi^*) + c_2 y_t + c_3 r_{t-1} + u_t \tag{3.3}$$

where π^* is the inflation target. The coefficient c_1 measures the intensity with which the central bank adjusts the interest rate when the observed inflation rate increases relative to the announced inflation target, and similarly c_2 measures the intensity with which the central bank raises the interest rate when the output gap increases. Finally, it is assumed that the central bank smooths the interest rate and this smoothing behavior is represented by the lagged interest rate in equation (3.3).

On the next step, heuristics are being introduced in forecasting output. It is assumed that agents use simple rules of behavior and they learn through "trial and error" (which is also called "adaptive learning").

Adaptive learning is a procedure where agents use simple forecasting rules and then they endogenously select the rules that have delivered the highest performance in the past. In the model it is assumed that there are two types of forecasting rules. The first type of rule is called a "fundamentalist" one, where agents estimate the steady-state value of the output gap (which is normalized at 0) and use this to forecast the future output gap. The second forecasting rule is an "extrapolative" one. Agents extrapolate previous observed output gap into the future. Those rules are specified as follows.

The fundamentalist rule is defined by:

$$\tilde{E}_t^f y_{t+1} = 0 \tag{3.4}$$

The extrapolative rule is defined by:

$$\tilde{E}_t^e y_{t+1} = y_{t-1} \tag{3.5}$$

The market forecast is obtained as a weighted average of these two forecasts,

$$\tilde{E}_t y_{t+1} = \alpha_{f,t} \tilde{E}_t^f y_{t+1} + \alpha_{e,t} \tilde{E}_t^f \tag{3.6}$$

$$\tilde{E}_t y_{t+1} = \alpha_{f,t} 0 + \alpha_{e,t} y_{t-1} \tag{3.7}$$

$$\alpha_{f,t} + \alpha_{e,t} = 1 \tag{3.8}$$

where $\alpha_{f,t}$ and $\alpha_{e,t}$ are the probabilities that agents use a fundamentalist and an extrapolative rule, respectively.

In the following step, agents compute the forecast performance of the two different forecasting rules as follows:

$$U_{f,t} = -\sum_{k=0}^{\infty} \omega_k [y_{t-k-1} - \tilde{E}_{f,t-k-2} y_{t-k-1}]^2 \tag{3.9}$$

$$U_{e,t} = -\sum_{k=0}^{\infty} \omega_k [y_{t-k-1} - \tilde{E}_{e,t-k-2} y_{t-k-1}]^2 \tag{3.10}$$

where $U_{f,t}$ and $U_{e,t}$ are the forecast performances (utilities) of the fundamentalist and extrapolating rules, respectively. The weights are declining, because it assumed that agents tend to forget. They give a lower weight to errors made far in the past as compared with errors made recently.

Continuing on, we add discrete choice theory (see Anderson et al. (1992)) in order to specify the procedure agents follow in this evaluation process. If agents were rational the would just compare the forecast utilities and choose the one with the highest value. But, psychologists have found out that when individuals choose among different choices, they are influenced by their state of mind, which cannot be predicted easily. In order to formalize this, we break the utilities into two components, the deterministic component ($U_{f,t}$ and $U_{e,t}$) and a random component $\epsilon_{f,t}$ and $\epsilon_{e,t}$. The probability of choosing the fundamentalist rule is then given by

$$\alpha_{f,t} = P[U_{f,t} + \epsilon_{f,t} > (U_{e,t} + \epsilon_{e,t})] \tag{3.11}$$

This means that the probability of selecting the fundamentalist rule is equal to the probability that the stochastic utility associated with using the fundamentalist rule exceeds the stochastic utility of using an extrapolative rule. In the discrete choice literature it is assumed that these random variables are distributed logistically (Anderson et al. 1992, p.35). Then following the expressions for the probability of choosing the fundamentalist rule is defined as

$$\alpha_{f,t} = \frac{\exp(\gamma U_{f,t})}{\exp(\gamma U_{f,t}) + \exp(\gamma U_{e,t})} \tag{3.12}$$

and the the probability that an agent will use the extrapolative rule is:

$$\alpha_{f,t} = \frac{\exp(\gamma U_{e,t})}{\exp(\gamma U_{f,t}) + \exp(\gamma U_{e,t})} = 1 - \alpha_{f,t} \tag{3.13}$$

where γ measures the "intensity of choice" and it is related to the variance of the random components $\epsilon_{f,t}$ and $\epsilon_{e,t}$. If the variance is very high, γ approaches to 0. In this case the probabilities of agents choosing either one of the rules are equal. If $\gamma = \infty$, then the variance of the random components is zero and the probability of using a fundamentalist rule is either 1 or 0. The parameter γ can also be interpreted as expressing a willingness to learn from the past and as the willingness increases, the size of γ also increases.

In addition, agents are also required to forecast inflation by using a similar method as in the case of output gap foresting. Again, there are two types of rules the fundamentalist one and the extrapolative one. It is assumed that an institutional setup in which in which the central bank announces an explicit inflation target. Agents who trust the announcement use fundamentalist rule, while agents who do not trust use the extrapolative rule.

The fundamentalist rule will be called an "inflation targeting" rule and it is given by

$$\tilde{E}_t^{\text{tar}} \pi_{t+1} = \pi^* \tag{3.14}$$

where the inflation target π^* normalized to be equal to 0.
The "extrapolators" are defined by

$$\tilde{E}_t^{\text{ext}} \pi_{t+1} = \pi_{t-1} \tag{3.15}$$

The market forecast is a weighted average of these two forecasts, i.e.,

$$\tilde{E}_t \pi_{t+1} = \beta_{\text{tar},t} \tilde{E}_t^{\text{tar}} \pi_{t+1} + \beta_{\text{ext},t} \tilde{E}_t^{\text{ext}} \pi_{t+1} \tag{3.16}$$

or

$$\tilde{E}_t \pi_{t+1} = \beta_{\text{tar},t} \pi^* + \beta_{\text{ext},t} \pi_{t-1} \tag{3.17}$$

and

$$\beta_{\text{tar},t} + \beta_{\text{ext},t} = 1 \tag{3.18}$$

The probabilities are given by:

$$\beta_{\text{tar},t} = \frac{\exp(\gamma U_{\text{tar},t})}{\exp(\gamma U_{\text{tar},t}) + \exp(\gamma U_{\text{ext},t})} \tag{3.19}$$

$$\beta_{\text{ext},t} = \frac{\exp(\gamma U_{\text{ext},t})}{\exp(\gamma U_{\text{tar},t}) + \exp(\gamma U_{\text{ext},t})} \tag{3.20}$$

where $U_{\text{tar},t}$ and $U_{\text{ext},t}$ are the forecast performances (utilities) associated with the use of the fundamentalist and extrapolative rules.

The solution of the model is found by first substituting (3.3) into (3.1) and rewriting in matrix notation:

$$\begin{bmatrix} 1 & -b_2 \\ -a_2c_1 & 1-a_2c_2 \end{bmatrix} \begin{bmatrix} \pi_t \\ y_t \end{bmatrix} = \begin{bmatrix} 0 & b_1 \\ -a_2 & a_1 \end{bmatrix} \begin{bmatrix} \tilde{E}_t\pi_{t+1} \\ \tilde{E}_t y_{t+1} \end{bmatrix} + \begin{bmatrix} 1-b_1 & 0 \\ 0 & 1-a_1 \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ y_{t-1} \end{bmatrix} + \begin{bmatrix} 0 \\ a_2c_3 \end{bmatrix} r_{t-1} + \begin{bmatrix} \eta_t \\ a_2u_t + \epsilon_t \end{bmatrix}$$

or

$$\boldsymbol{A}\boldsymbol{Z}_t = \boldsymbol{B}\tilde{\boldsymbol{E}}_t\boldsymbol{Z}_{t+1} + \boldsymbol{C}\boldsymbol{Z}_{t-1} + \boldsymbol{b}r_{t-1} + \boldsymbol{v}_t \tag{3.21}$$

where the bold characters refer to matrices and vectors. The solution for $\boldsymbol{Z}_t$ is given by

$$\boldsymbol{Z}_t = \boldsymbol{A}^{-1}[\boldsymbol{B}\tilde{\boldsymbol{E}}_t\boldsymbol{Z}_{t+1} + \boldsymbol{C}\boldsymbol{Z}_{t-1} + \boldsymbol{b}r_{t-1} + \boldsymbol{v}_t] \tag{3.22}$$

Chapter 4

Data

In this chapter we are going to describe the way we gather data and the methodologies used to process them before their use in the model.

4.1 Data Collection

We gathered annual data for GDP, quarterly data of inflation, and monthly data for the CPI (Consumer Confidence Index) for the countries of Greece, Ireland, Italy, and Spain for the periods 1985 until 2015. The data was collected from the OECD database.

4.2 Data Analysis

Before using the data in the model, we had to calculate the output gap. There were fours methods with which we tried to estimate the output gap. The first method we used in order to calculate the output gap is the Hodrick-Prescott (HP) filtration (1997). In the Figure 4.1 we can see the result.

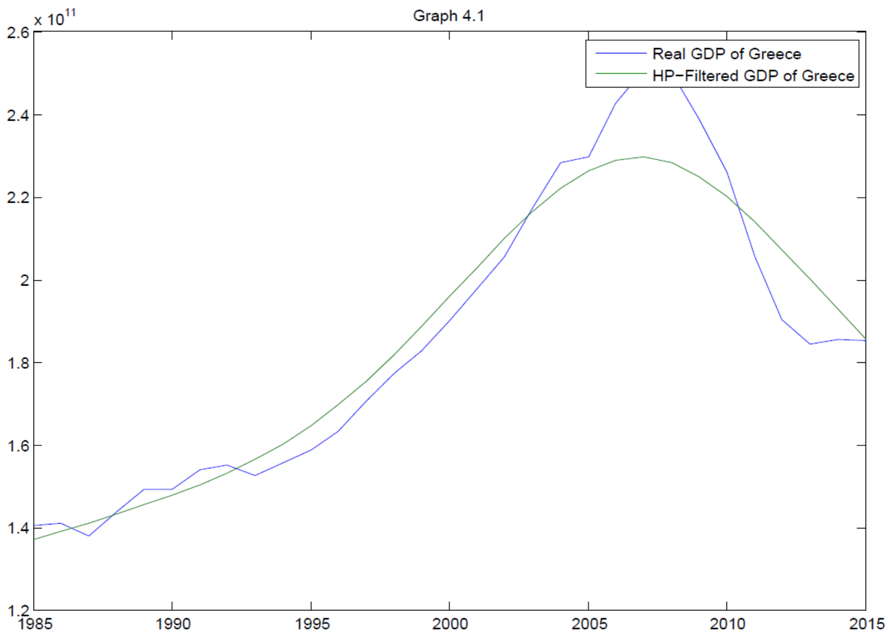

FIGURE 4.1: GDP and Potential GDP of Greece using HP-filter.

For the second method, we tried to use the HP-filter to estimate the natural rate of unemployment. Then we used Okun's Law (1963) to calculate the potential output. The results are presented on the Figure 4.2.

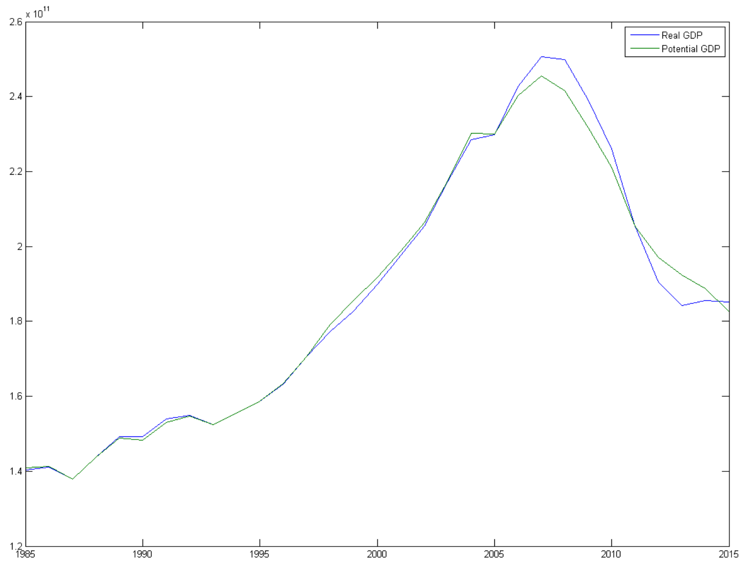

FIGURE 4.2: GDP and Potential GDP of Greece using Okun's Law.

In the third approach, we applied the Kalman filter, which was suggested by Rudolf E. Kálmán (1960), on the output of Greece. Figure 4.3 shows the result.

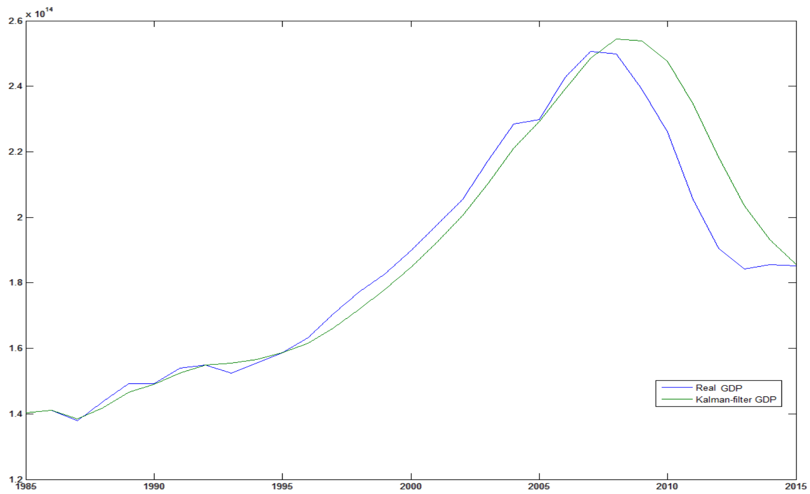

FIGURE 4.3: GDP and Potential GDP of Greece using Kalman filtration.

Finally, in the last approach, we used the Kalman filtration to estimate the natural rate of unemployment and later used the estimated natural rate of unemployment to calculate the potential output. The result is shown on the Figure 4.4.

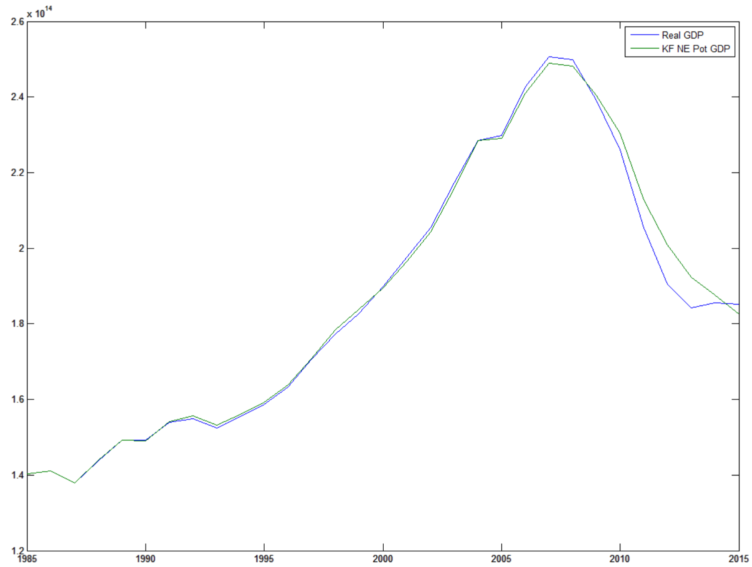

FIGURE 4.4: GDP and Potential GDP of Greece using Kalman filtration on the natural rate of unemployment.

For the model we chose the first method. We calculated the annual output gap for the periods 1985 until 2015 and then transformed the annual results into quarterly. For the quarterly conversion we used to method of cubic spline interpolation. In the figures below are shown the output gaps annually and quarterly.

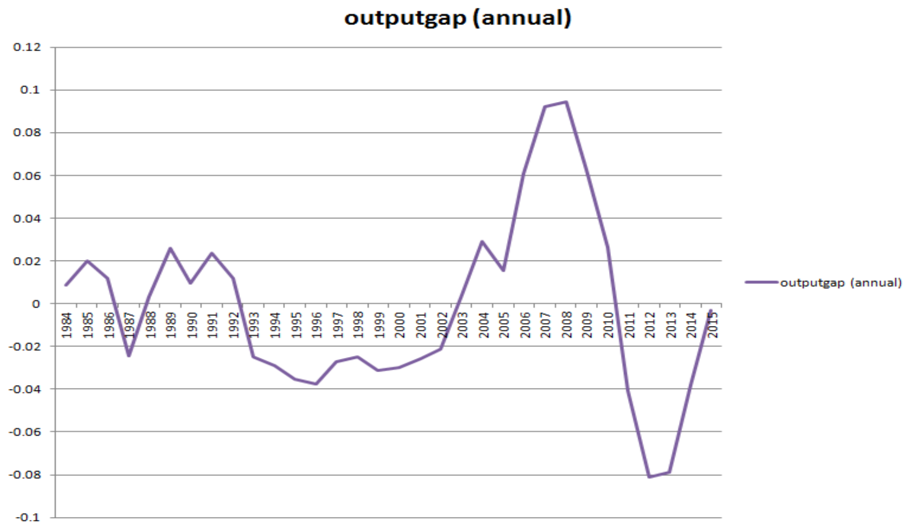

FIGURE 4.5: Output gap of Greece using annual data.

For the cubic spline interpolation the Econometric Views software was used to perform the conversion.

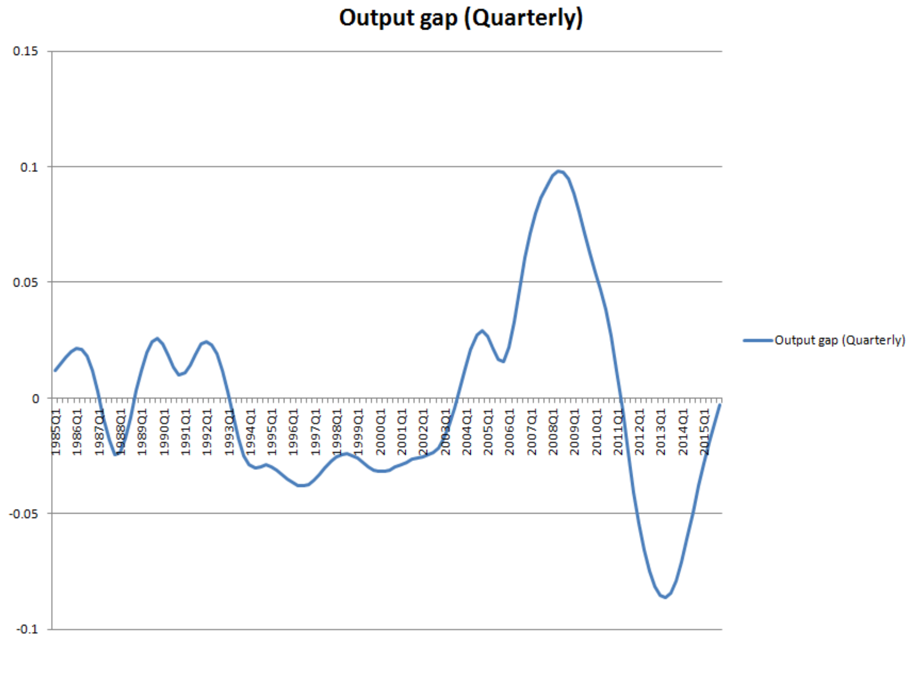

FIGURE 4.6: Quarterly representation of output gap of Greece.

For the countries of Ireland, Italy and Spain we used similar method. We used the Hodrick-Prescott filtration to estimate the potential output of these countries and then used it to calculate the output gap. Lastly, we used the cubic spline interpolation to convert the annual output gap results into quarterly. Since the data for the CPI was in monthly form, again, we used the cubic spline interpolation to convert the monthly data into quarterly.

Obviously, the results that we will obtain, will not be consistent, since we were not able to find all the data required for these countries in quarterly form. The estimated will most likely produce inconsistent results in the model.

Chapter 5

Empirical Analysis

5.1 Calibration

In this section we are going to use the data analyzed in the previous chapter in the behavioral macroeconomic model. We will begin with Greece. We calibrate the behavioral model for Greece using the output gap and the inflation rate. The parameters that were used in the calibration are presented in the table 5.1. The Matlab code that was used is provided in the appendix.

TABLE 5.1: Parameter values that were used for calibration.

Parameters	**Values**
a_1	0.12
a_2	-0.54
b_1	0.98
b_2	0.97
c_1	1.08
c_2	1.5
c_3	0.86
σ_1 (standard deviation of shocks in output)	0.0005
σ_2 (standard deviation of shocks in inflation)	0.09
σ_3 (standard deviation of shocks in Taylor's rule)	0.0005
π^*	0.02
ρ (the speed of declining weights in mean squares errors)	0.02

On the figure 5.1 we can see the results of the calibration. The line of the calibrated output gap does not match with the one of the actual data. There can be numerous reasons for this issue. One of the reason, as we mentioned previously, is the lack of data and the use of estimated data. This probably has caused inconsistent results on the model. Of course, the issue could also lie in the behavioral model itself, but since we do not have the necessary data to confirm that we cannot be sure about the root of the problem. The same issue we can observe on the inflation graph. The calibrated inflation does not seem to show many deviations, while the inflation of the actual data does.

On the second attempt, we included the Consumer Confidence Index in the model. On the figure 5.2 we can observe the results. The calibrated output gap seems to be a bit closer to the estimated gap and the calibrated inflation rate seems to follow the inflation rate of the data up until 2008. After that the inflation rate seems to demonstrate sudden deviation, which is probably due to crisis and the model cannot simulate that shock.

FIGURE 5.1: Results of the calibrated behavioral model for Greece.

FIGURE 5.2: Calibrated model for Greece using CCI.

We repeated the same process for Ireland, Italy and Spain. On the table 5.2 are shown the calibration parameters for Ireland.

TABLE 5.2: Parameter values that were used for the calibration of Ireland.

Parameters	**Values**
a_1	0.19
a_2	-0.19
b_1	0.63
b_2	0.86
c_1	1.67
c_2	0.85
c_3	0.62
σ_1	0.0004
σ_2	0.09
σ_3	0.005
π^*	0.02
ρ	0.5

The results of the calibration are shown on the figure 5.3. We observe again the same issues we had for Greece. The output gap from calibrated model of Ireland presents increased deviations and the inflation rate shows sudden movements at the beginning of 2008. The reasons are most likely the same as mentioned before. On the figure 5.4 we ran the model using CCI. The outcome is not much different and the issues persist.

We apply the behavioral macroeconomic model on Italy and Spain as well. The tables 5.3 and 5.4 present the parameters that were used for each of the countries respectively. In the figures 5.5 and 5.6 we can see that the model is not fit to describe the output and inflation for Italy.

For Spain the results look much better. The output gap of the calibrated model seem to be more consistent for Spain. The figures 5.7 and 5.8 show the outcomes.

TABLE 5.3: Parameter values that were used for the calibration of Italy.

Parameters	**Values**
a_1	0.26
a_2	-0.34
b_1	0.4
b_2	0.06
c_1	1.75
c_2	0.25
c_3	0.2
σ_1	0.0002
σ_2	0.05
σ_3	0.004
π^*	0.02
ρ	0.02

TABLE 5.4: Parameter values that were used for the calibration of Spain.

Parameters	**Values**
a_1	0.19
a_2	-0.19
b_1	0.63
b_2	0.86
c_1	1.67
c_2	0.85
c_3	0.62
σ_1	0.0004
σ_2	0.09
σ_3	0.005
π^*	0.02
ρ	0.5

FIGURE 5.3: Calibration results for Ireland.

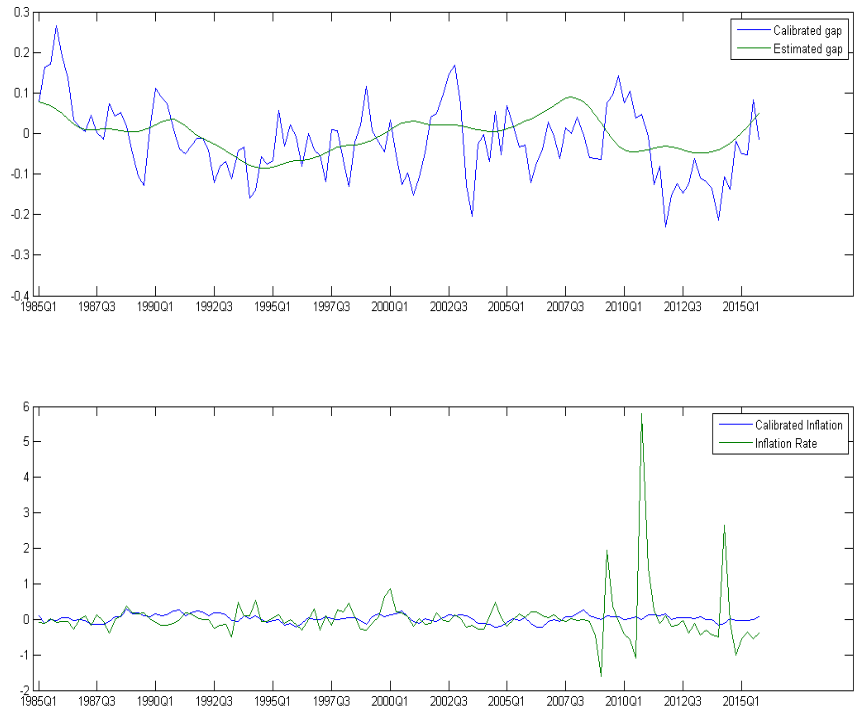

FIGURE 5.4: Calibration results for Ireland using CCI.

FIGURE 5.5: Calibration results for Italy.

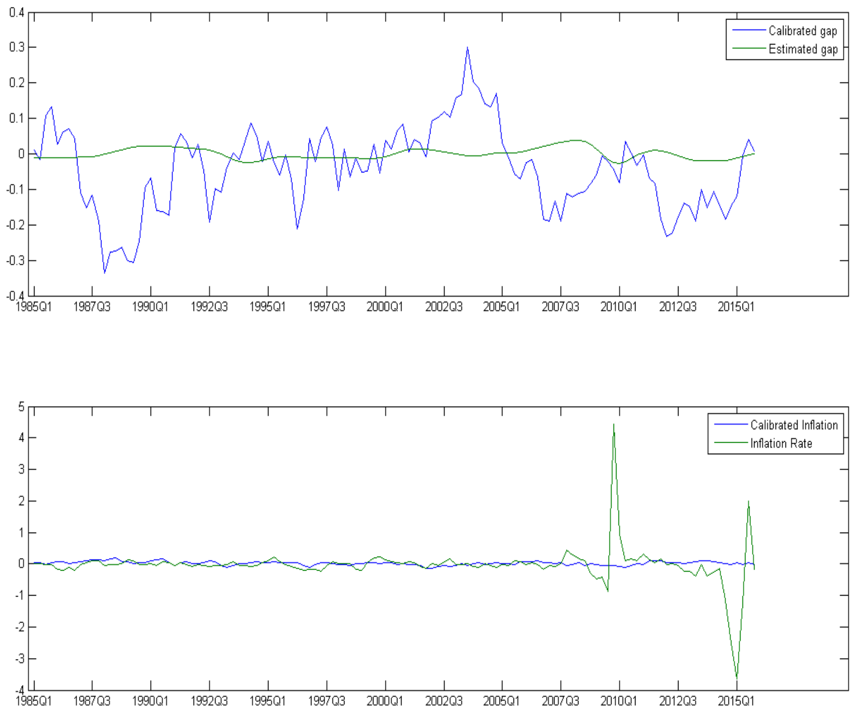

FIGURE 5.6: Calibration results for Italy using CCI.

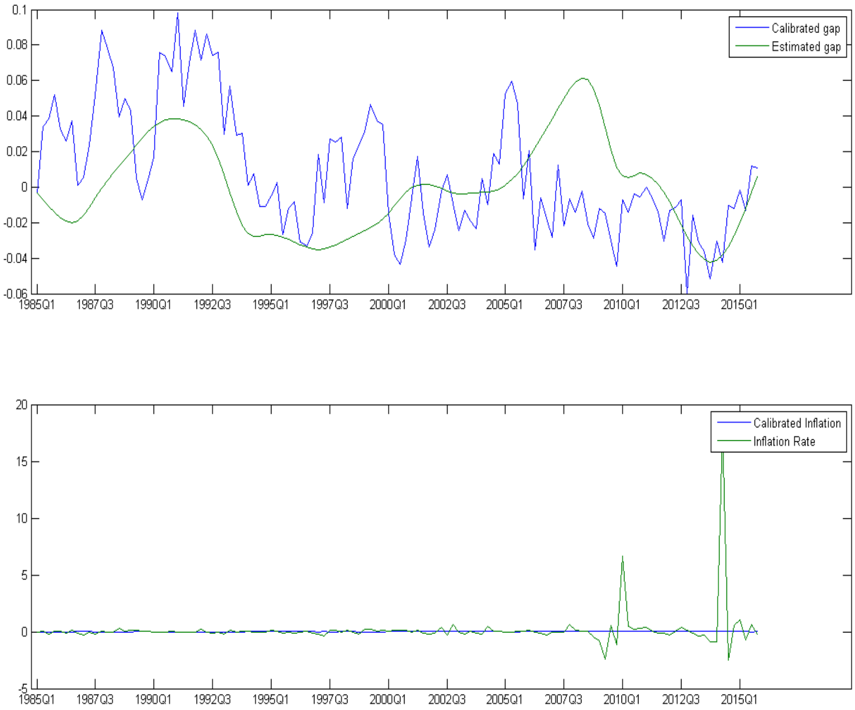

FIGURE 5.7: Calibration results for Spain.

FIGURE 5.8: Calibration results for Spain using CCI.

Chapter 6

Conclusion

The recent advancements in behavioral macroeconomics have provided a new scope regarding how macroeconomic models should be implemented. Previously established assumption are being slowly replaced by modern behavioral assumptions.

On this dissertation, we tried to present a new approach to the New Keynesian macroeconomic model, by using behavioral assumptions instead of the rational expectations assumptions. We attempted to apply the model on Greece, Ireland, Italy and Spain and compare the results. It seems that the model still requires a lot of room for improvement. The results we received after running the calibration were not consistent with the data. There could be many reasons that the model failed on the actual data, and one is most likely the lack of the data. We ended up estimating the output gap, since there were no quarterly data available and we had to use annual data to estimate the quarterly output gap. Of course this has caused issues on the calibration.

A more thorough analysis is needed with consistent data in order to test the validity of the model. Extensions of the model could also be suggested to produce better results.

Appendix A

Analytical Solution of the Model

A.1 The New Keynesian Model

In this section I will derive the behavioral model analytically based on Gali's (2008, chapter 2 & 3) New Keynesian model.

The representative household maximizes the following function

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{A.1}$$

where N_t are the hours of work or employment, and C_t is a consumption index given by

$$C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}$$

where $C_t(i)$ is the quantity of good i consumed in period t. We assume that the period utility $U(C_t, N_t)$ is continuous and twice differentiable with

$$U_{c,t} \equiv \frac{\partial U(C_t, N_t)}{\partial C_t} > 0, \quad U_{cc,t} \equiv \frac{\partial^2 U(C_t, N_t)}{\partial C_t^2} \leq 0$$
$$U_{n,t} \equiv \frac{\partial U(C_t, N_t)}{\partial N_t} \leq 0, \quad U_{nn,t} \equiv \frac{\partial^2 U(C_t, N_t)}{\partial N_t^2} \leq 0$$

The maximization of (23) is done under the following budget constraint

$$\int_0^1 P_t(i) C_t(i) di + Q_t B_t \leq B_{t-1} + W_t N_t + T_t, \quad \forall t \geq 0$$

where $P_t(i)$ denotes the price of the consumed good i, W_t is the nominal wage, B_t represents the quantity of one-period, nominally risk-less discount bonds purchased in period t and maturing in $t+1$. The bond pays one unit of money at maturity and its price is Q_t. The lump-sum additions or subtractions in nominal values are represented by T_t. The household takes as given the price of the good, the wage, and the price of bonds.

In order to avoid Ponzi type schemes, the household is subject to the following solvency constraint

$$\lim_{T \to \infty} E_t B_T \geq 0, \quad \forall t$$

The household needs to choose the consumption (and saving) levels and labor supply. In addition, it must decide how to allocate its consumption expenditures among the different goods. Thus, it maximizes C_t for any given expenditure level

$$\int_0^1 P_t(i)C_t(i)di \equiv Z_t$$

Hence, the Lagrangian takes the form

$$\mathcal{L} = \Big[\int_0^1 C_t(i)^{1-\frac{1}{\epsilon}}di\Big]^{\frac{\epsilon}{\epsilon-1}} - \lambda\Big(\int_0^1 P_t(i)C_t(i)di - Z_t\Big)$$

The first order conditions are

$$\frac{\partial \mathcal{L}}{\partial C_t(i)} = 0 \Rightarrow C_t(i)^{-\frac{1}{\epsilon}} C_t^{\frac{1}{\epsilon}} = \lambda P_t(i), \quad \forall i \in [0,1]$$

For $j \neq i$ we have

$$C_t(j)^{-\frac{1}{\epsilon}} C_t^{\frac{1}{\epsilon}} = \lambda P_t(j)$$

By dividing the last two, we get the following expression for two goods (i, j)

$$C_t(i) = C_t(j)\Big(\frac{P_t(i)}{P_t(j)}\Big)^{-\epsilon}$$

and we substitute it into consumption expenditure and we get

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon}\frac{Z_t}{P_t}, \quad \forall i \in [0,1]$$

Finally, we substitute the last expression into the definition of C_t and we have

$$\int_0^1 P_t(i)C_t(i)di = P_t C_t$$

Combining the last two expressions we obtain

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t \quad \forall i \in [0,1] \tag{A.2}$$

where $P_t \equiv [\int_0^1 P_t(i)^{1-\epsilon}di]^{\frac{1}{1-\epsilon}}$ is the aggregate price index. Substituting the previous expression in the budget constraint yields

$$P_t C_t + Q_t B_t \leq B_{t-1} + W_t N_t + T_t, \quad \forall t \geq 0 \tag{A.3}$$

Now, maximizing (A.1) subject to (A.2) we get the following first order conditions:

$$U_{c,t} - \lambda_t P_t = 0$$

$$U_{n,t} - \lambda_t W_t = 0$$

$$Q_t = \beta\frac{\lambda_{t+1}}{\lambda_t}$$

Combining and substituting the above conditions we receive the following expressions

$$-\frac{U_{n,t}}{U_{c,t}} = \frac{W_t}{P_t} \tag{A.4}$$

$$Q_t = \beta E_t\left\{\frac{U_{c,t+1}}{U_{c,t}}\frac{P_t}{P_{t+1}}\right\} \quad \forall t \geq 0 \tag{A.5}$$

It is assumed that the period utility is given by

$$U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \tag{A.6}$$

where

$$U_{c,t} = C_t^{-\sigma} \tag{A.7}$$

$$U_{n,t} = -N_t^{\phi} \tag{A.8}$$

Substituting (A.6) and (A.7) in (A.3) and (A.4) we get

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\phi} \tag{A.9}$$

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{A.10}$$

The Euler equation can be written as follows

$$1 = E_t\{\exp(r_t - \sigma \Delta c_{t+1} - \pi_{t+1} - \rho)\} \tag{A.11}$$

where $r_t \equiv -\log Q$ is the nominal interest rate, $\rho \equiv -\log \beta$ is the discount rate, $\pi_{t+1} \equiv p_{t+1} - pt$ is the inflation rate. In a perfect foresight steady state with constant inflation π and growth rate γ

$$r = \rho + \pi + \sigma\gamma$$

and the steady state real rate is given by

$$\begin{aligned} i &\equiv r - \pi \\ &= \rho + \sigma\gamma \end{aligned}$$

If we take a first order Taylor expansion of $\exp(r_t - \sigma \Delta c_{t+1} - \pi_{t+1} - \rho)$ around the state we receive the following result

$$\begin{aligned} \exp(r_t - \sigma \Delta c_{t+1} - \pi_{t+1} - \rho) &\simeq 1 + (i_t - i) - \sigma(\Delta c_{t+1} - \gamma) - (\pi_{t+1} - \pi) \\ &= 1 + i_t - \sigma \Delta c_{t+1} - \pi_{t+1} - \rho \end{aligned}$$

which we substitute in (A.10) and we obtain the log-linear Euler equation

$$c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}(r_t - E_t\{\pi_{t+1}\} - \rho) \tag{A.12}$$

By log-linearizing (A.8) we obtain

$$w_t - p_t = \sigma c_t + \phi n_t \tag{A.13}$$

In addition, we will introduce one more condition, the demand for real balances, which is given in log-linear form as

$$m_t - p_t = y_t - \eta i_t \tag{A.14}$$

On the next step we will analyze the behavior of firms. We assume there a continuum number of firms, each of them represented by a point i such that $i \in [0, 1]$. Every firm produces a different good, but they share the same technology and each firm's production function is given by

$$Y_t(i) = A_t N_t(i)^{1-\alpha} \tag{A.15}$$

where A_t is the level of technology which is the same among the firms and grows exogenously over time. The firms take as given the aggregate price and consumption levels, and face the demand given by (A.2).

Based on Calvo (1983), where it is assumed that a firm can only change its price when a price-signal is received, at some probability. That probability is independent from the last time the firm received the signal. Following the same approach, we assume that each firm may change its price with probably $1-\theta$. Hence, a portion $1-\theta$ of the firms reset their prices, while a fraction θ keep their prices unchanged.

We denote the set of firms, who do not optimize their posted price in period t with $S(t) \subset [0,1]$. Combining the definition of aggregate price level and the fact that all firms who change their prices will choose the same price level P_t^*, we end up with the following expression

$$\begin{aligned} P_t &= \left[\int_{S(t)} P_{t-1}(i)^{1-\epsilon} di + (1-\theta)(P_t^*)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \\ &= \left[\theta (P_{t-1})^{1-\epsilon} + (1-\theta)(P_t^*)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \end{aligned}$$

By dividing both sides by P_{t-1} we obtain

$$\Pi_t^{1-\epsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}} \right)^{1-\epsilon} \tag{A.16}$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$, is the gross inflation rate between $t-1$ and t. In the case where we have zero inflation, in the steady state we have $P_t^* = P_{t-1} = P_t, \ \forall t$. By log linearizing the above equation around $\Pi_t = 1$ and $\frac{P_t^*}{P_{t-1}} = 1$ we get

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}). \tag{A.17}$$

The problem that a firm solves in period t is

$$\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k E_t \Big\{ Q_{t,t+k} \big(P_t^* Y_{t+k|t} - \Psi_{t+k}(Y_{t+k|t}) \big) \Big\} \tag{A.18}$$

$$\text{s.t. } Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}} \right)^{-\epsilon} C_{t+k}, \quad \text{for } k = 0, 1, 2, ... \tag{A.19}$$

where $Q_{t,t+k} \equiv \beta^k (C_{t+k}/C_t)^{-\sigma}(P_t/P_{t+k})$ is the stochastic discount factor for nominal pay-offs, $\Psi(\cdot)$ is the cost function, $Y_{t+k|t}$ is the output in $t+k$ for the firm that changed its price in period t and (A.19) is the sequence of demand constraints.

The first order condition take the form

$$\sum_{k=0}^{\infty} \theta^k E_t \Big\{ Q_{t,t+k} Y_{t+k|t} (P_t^* - \mathcal{M} \psi_{t+k|t}) \Big\} = 0 \tag{A.20}$$

where $\psi_{t+k|t} \equiv \Psi'_{t+k}(Y_{t+k|t})$ is the marginal nominal cost in period $t+k$ and $\mathcal{M} \equiv \frac{\epsilon}{\epsilon - 1}$.

Dividing (A.20) by P_{t-1} we get

$$\sum_{k=0}^{\infty}\theta^k E_t\left\{Q_{t,t+k}Y_{t+k|t}\left(\frac{P_t^*}{P_{t-1}}-\mathcal{M}MC_{t+k|t}\Pi_{t-1,t+k}\right)\right\} \tag{A.21}$$

where $\Pi_{t,t+k} \equiv P_{t+k}/P-t$ and $MC_{t+k|t} \equiv \psi_{t+k|t}/P_{t+k}$ is the real marginal cost. We linearize (A.20) around zero inflation. In the zero inflation steady state $P_t^*/P_{t-1}=1$ and $\Pi_{t-1,t+k}=1$, which implies that $P_t^*=P_{t+k}$, $Y_{t+k|t}=Y$, $MC_{t+k|t}=MC$ and $Q_{t,t+k}=\beta^k$. In addition, it follows that $MC=1/\mathcal{M}$. By performing a first order Taylor expansion of the previous expression around the steady state, it leads to

$$p_t^*-p_{t-1}=(1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\hat{mc}_{t+k|t}+(p_{t+k}-p_{t-1})\} \tag{A.22}$$

where $\hat{mc}_{t+k|t} \equiv mc_{t+k|t}-mc$ is the log deviation of the marginal cost from its steady state $mc=-\mu$, where $\mu \equiv \log\mathcal{M}$ is the log of the desired gross markup.

In the equilibrium, the market clearing condition for goods is

$$Y_t(i)=C_t(i), \quad \forall i\in[0,1]$$

We define the aggregate output as

$$Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\epsilon}}di\right)^{\frac{\epsilon}{\epsilon-1}}$$

It follows that

$$Y_t=C_t$$

Combining the above market clearing conditions with Euler equation yields

$$y_t=E_t\{y_{t+1}\}-\frac{1}{\sigma}(r_t-E_t\{\pi_{t+1}\}-\rho) \tag{A.23}$$

The market clearing condition for the labor market is

$$N_t=\int_0^1 N_t(i)di \tag{A.24}$$

Substituting (A.15) in (A.24) yields

$$\begin{aligned} N_t &= \int_0^1\left(\frac{Y_t(i)}{A_t}\right)^{\frac{1}{1-\alpha}}di \\ &= \left(\frac{Y_t}{A_t}\right)^{\frac{1}{1-\alpha}}\int_0^1\left(\frac{P_t(i)}{P_t}\right)^{-\frac{\epsilon}{1-\alpha}}di \end{aligned}$$

By using logarithms, we have that

$$(1-\alpha)n_t=y_t-a_t+d_t$$

where $d_t \equiv (1-\alpha)\log\int_0^1(P_t(i)/P_t)^{-\frac{\epsilon}{1-\alpha}}$ and di is a measure of price dispersion across firms.

The approximation of the previous relation can be written as

$$y_t=a_t+(1-\alpha)n_t \tag{A.25}$$

The expression for an individual firm's marginal cost in terms of the economy's average real marginal cost is defined as

$$\begin{aligned} mc_t &= (w_t - p_t) - mpn_t \\ &= (w_t - p_t) - (a_t - \alpha n_t) - \log(1-\alpha) \\ &= (w_t - p_t) - \frac{1}{1-\alpha}(a_t - \alpha y_t) - \log(1-\alpha) \end{aligned}$$

where the second equality defines the economy's average marginal product of labor,mpn_t, in a consistent way with (A.25). For $t+k$ we have

$$\begin{aligned} mc_{t+k|t} &= (w_{t+k} - p_{t+k}) - mpn_{t+k|t} \\ &= (w_{t+k} - p_{t+k}) - -\frac{1}{1-\alpha}(a_{t+k} - \alpha y_{t+k|t}) - \log(1-\alpha) \end{aligned}$$

Combining the above with (A.24) and the market clearing condition for goods yields

$$\begin{aligned} mc_{t+k|t} &= mc_{t+k} + \frac{\alpha}{1-\alpha}(y_{t+k|t} - y_{t+k}) \\ &= mc_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p_t^* - p_{t+k}) \end{aligned} \tag{A.26}$$

Substituting (A.26) in (A.22) and rearranging we have

$$\begin{aligned} p_t^* - p_{t-1} &= (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\Theta\hat{mc}_{t+k} + (p_{t+k} - p_{t-1})\} \\ &= (1-\beta\theta)\Theta\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\hat{mc}_{t+k}\} + \sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\pi_{t+k}\} \end{aligned}$$

where $\Theta \equiv \frac{1-\alpha}{1-\alpha+\alpha\epsilon} \leq 1$. Rewriting it as a difference equation

$$p_t^* - p_{t-1} = \beta\theta E_t\{p_{t+1}^* - p_t\} + (1-\beta\theta)\Theta\hat{mc}_t + \pi_t \tag{A.27}$$

Combining (A.17) and (A.27) yields

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \lambda\hat{mc}_t \tag{A.28}$$

where $\lambda \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}\Theta$.

Solving the above forward, inflation is expressed as the discounted sum of current and expected future deviations of real marginal costs from steady state

$$\pi_t = \lambda\sum_{k=o}^{\infty}\beta^k E_t\{\hat{mc}_{t+k}\}$$

The relation between the economy's real marginal cost and a measure of aggregate economic activity can be derived using (A.13) and (A.25)

$$\begin{aligned} mc_t &= (w_t - p_t) - mpn_t \\ &= (\sigma y_t + \phi n_t) - (y_t - n_t) - \log(1-\alpha) \\ &= \left(\sigma + \frac{\phi+\alpha}{1-\alpha}\right)y_t - \frac{1+\phi}{1-\alpha}a_t - \log(1-\alpha) \end{aligned} \tag{A.29}$$

We define the natural of output as the equilibrium level of output under flexible prices denoted as y_t^n

$$mc = \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right) y_t^n - \frac{1 + \phi}{1 - \alpha} a_t - \log(1 - \alpha) \tag{A.30}$$

$$\Rightarrow y_t^n = \psi_{ya}^n a_t + \theta_y^n \tag{A.31}$$

where $\theta_y^n \equiv -\frac{(1-\alpha)(\mu - \log(1-\alpha))}{\sigma(1-\alpha)+\phi+\alpha} > 0$, $\psi_{ya}^n \equiv \frac{1+\phi}{\sigma(1-\alpha)+\phi+\alpha}$ and $\mu = -mc$.

By subtracting (A.30) from (A.29) we get

$$\hat{mc}_t = \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right)(y_t - y_t^n) \tag{A.32}$$

which the log deviation of real marginal cost from steady state is proportional to the log deviation of output from its flexible price counterpart.

We define the output gap as $\tilde{y}_t \equiv y_t - y_t^n$. Combining (A.28) and (A.32) obtains

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa \tilde{y}_t \tag{A.33}$$

where $\kappa \equiv \lambda(\sigma + \frac{\phi+\alpha}{1-\alpha})$ and (A.33) is known as the New Keynesian Phillips curve.

Finally, the last equation of the New Keynesian model that describes the equilibrium is defined by rewriting (A.23) in terms of output gap

$$\tilde{y} = -\frac{1}{\sigma}(r_t - E_t\{\pi_{t+1}\}) + E_t\{\tilde{y}_{t+1}\} \tag{A.34}$$

Rewriting (A.33) and (A.34) for the behavioral model and adding error terms we obtain

$$\tilde{y}_t = \tilde{E}_t \tilde{y}_{t+1} + \alpha_2(r_t - \tilde{E}_t \pi_{t+1}) + \epsilon_t \tag{A.35}$$

$$\pi_t = \beta \tilde{E}_t \pi_{t+1} + \kappa \tilde{y}_t + \eta_t \tag{A.36}$$

where ϵ_t and η_t are the white noise disturbance terms. Furthermore, since in the real world consumers do not adjust their optimal plans immediately, we introduce habit formation (see Smets and Wouters(2007)). This will add an additional lag in the demand equation, thus

$$\tilde{y}_t = \alpha_1 \tilde{E}_t \tilde{y}_{t+1} + (1 - \alpha_1) y_{t-1} + \alpha_2(r_t - \tilde{E}_t \pi_{t+1}) + \epsilon_t$$

Appendix B

MATLAB Codes Used for the Thesis

On this appendix I will present the MATLAB codes that were used for the filtration and the analysis of the data, and in the calibration of the behavioral model.

```
The HP-filter which was created by Ivailo Izvorski:
function [s]=hpfilter(y,w)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Author: Ivailo Izvorski,
%          Department of Economics
%    Yale University.
%          izvorski@econ.yale.edu
%  This code has been used and seems to be free of error.
%  However, it carries no explicit or implicit guarantee.
%
%  function [s]=hpfilter(y,w)
%  Hondrick Prescott filter where:
%  w - smoothing parameter; w=1600 for quarterly data
%  y - the original series that has to be smoothed
%  s - the filtered series
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if size(y,1)<size(y,2)
y=y';
end
t=size(y,1);
a=6*w+1;
b=-4*w;
c=w;
d=[c,b,a];
d=ones(t,1)*d;
m=diag(d(:,3))+diag(d(1:t-1,2),1)+diag(d(1:t-1,2),-1);
m=m+diag(d(1:t-2,1),2)+diag(d(1:t-2,1),-2);
%
m(1,1)=1+w;        m(1,2)=-2*w;
m(2,1)=-2*w;       m(2,2)=5*w+1;
m(t-1,t-1)=5*w+1;  m(t-1,t)=-2*w;
m(t,t-1)=-2*w;     m(t,t)=1+w;
%
s=inv(m)*y;
```

The Kalman filteration code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [k,s] = kfilter(A,C,V1,V2,V12)

%function [k,s] = kfilter(A,C,V1,V2,V12)

%KFILTER can have arguments: (A,C,V1,V2) if there are no cross

% products, V12=0.
% Author: Alexander Meyer-Gohde (Humboldt University Berlin)
%     KFILTER calculates the kalman gain, k, and the stationary
%     covariance matrix, s, using the Kalman filter for:
%
% x[t+1] = Ax[t] + Bu[t] + w1[t+1]
%               y[t] = Cx[t] + Du[t] + w2[t]
%
%               E [w1(t+1)] [w1(t+1)]' =  [V1   V12;
%                 [ w2(t) ] [ w2(t) ]      V12' V2 ]
%
%  where x is the mx1 vector of states, u is the nx1 vector of controls,
%  y is the px1 vector of observables, A is mxm, B is mxn,
%  C is pxm, V1 is mxm,V2 is pxp, V12 is mxp.

m=max(size(A));
[rc,cc]=size(C);
if nargin==4; V12=zeros(m,rc); end;
if (rank(V2)==rc);
A=A-(V12/V2)*C;
V1=V1-V12*(V2\V12');
[k,s]=doubleo(A,C,V1,V2);
k=k+(V12/V2);
else;
s0=.01*eye(m);
dd=1;
it=1;
maxit=1000;
while (dd>1e-8 & it<=maxit);
k0= (A*s0*C'+V12)/(V2+C*s0*C');
s1= A*s0*A' + V1 -(A*s0*C'+V12)*k0';
k1= (A*s1*C'+V12)/(V2+C*s1*C');
dd=max(max(abs(k1-k0)));
it=it+1;
s0=s1;
end;
k=k1;s=s0;
if it>=maxit;
disp('WARNING: Iteration limit of 1000 reached in KFILTER.M');
end;
end;
```

The following is the behavioral macroeconomic model code taken from De Grauwe (2012). I have done some modifications and error fixes on the code in order to run to smoothly.

```
%% Parameters of the model
mm = 1; %switching parameter gamma in Brock Hommes
pstar = 0; % the central bank's inflation target
eprational=0; % if all agents have rational forecast of inflation this is 1
epextrapol=0; % if all agents use inflation extrapolation this parameter is 1
a1 = 0.5; %coefficient of expected output in output equation
a2 = -0.2; %a is the interest elasticity of output demand
b1 = 0.5; %b1 is coefficient of expected inflation in inflation equation
b2 = 0.05; %b2 is coefficient of output in inflation equation
c1 = 1.5; %c1 is coefficient of inflation in Taylor equation
c2 = 0.5; %c2 is coefficient of output in Taylor equation
c3 = 0.5; %interest smoothing parameter in Taylor equation
A = [1 -b2;-a2*c1 1-a2*c2];
B = [b1 0;-a2 a1];
C = [1-b1 0;0 1-a1];
T = 124;
TI = 124;
K = 50; %length of period to compute divergence
sigma1 = 0.5; %standard deviation shocks output
sigma2 = 0.5; %standard deviation shocks inflation
sigma3 = 0.5; %standard deviation shocks Taylor
rho=0.5; %rho in mean squares errors
rhoout=0.0; %rho in shocks output
rhoinf=0.0; %rho in shocks inflation
rhotayl=0.0; %rho in shocks Taylor
rhoBH=0.0;
epfs=pstar; %forecast inflation targeters
p = zeros(T,1);
y = zeros(T,1);
y(1,1)=0
p(1,1)=0
plagt = zeros(T,1);
ylagt = zeros(T,1);
r = zeros(T,1);
epf = zeros(T,1);
epc = zeros(T,1);
ep = zeros(T,1);
ey = zeros(T,1);
CRp = zeros(T,1);
FRp = zeros(T,1);
alfapt = zeros(T,1);
eyfunt = zeros(T,1);
CRy = zeros(T,1);
FRy = zeros(T,1);
alfayt = zeros(T,1);
anspirits = zeros(T,1);
epsilont = zeros(T,1);
etat = zeros(T,1);
ut = zeros(T,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%heuristic model
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
alfap=0.5;
alfay=0.5;
K1=K+1;
for t=2:T
```

```
epsilont(t) = rhoout*epsilont(t-1) + sigma1*randn; %shocks in output
equation (demand shock)
etat(t)= rhoinf*etat(t-1) + sigma2*randn; %shocks in inflation equation
(supply shock)
ut(t) = rhotayl*ut(t-1) + sigma3*randn; %shocks in Taylor rule
(interest rate shock)

epsilon = epsilont(t);
eta = etat(t);
u = ut(t);
shocks = [eta;a2*u+epsilon];
epcs=p(t-1);
if eprational==1;
epcs=pstar;
end
eps=alfap*epcs+(1-alfap)*epfs;
if epextrapol==1;
eps=p(t-1);
end
eychar=y(t-1);
eyfun=0+randn/2;
eyfunt(t)=eyfun;
eys=alfay*eychar+(1-alfay)*eyfun;
forecast = [eps;eys];
plag=p(t-1);
ylag=y(t-1);
rlag=r(t-1);
lag = [plag;ylag];
smooth = [0;a2*c3];
D = B*forecast + C*lag + smooth*rlag + shocks;
X = A\D;
p(t)= X(1,1);
y(t)= X(2,1);
r(t)= c1*p(t)+c2*y(t)+c3*r(t-1)+u;

plagt(t)=p(t-1);
ylagt(t)=y(t-1);
CRp(t) = rho*CRp(t-1) - (1-rho)*(epcs-p(t))^2;
FRp(t) = rho*FRp(t-1) - (1-rho)*(epfs-p(t))^2;
CRy(t) = rho*CRy(t-1) - (1-rho)*(eychar-y(t))^2;
FRy(t) = rho*FRy(t-1) - (1-rho)*(eyfun-y(t))^2;
alfap = rhoBH*alfapt(t-1)+(1-rhoBH)*exp(mm*CRp(t))/(exp(mm * CRp(t))
+ exp(mm * FRp(t)));

alfay = rhoBH*alfayt(t-1)+(1-rhoBH)*exp(mm*CRy(t))/(exp(mm * CRy(t))
+ exp(mm * FRy(t)));

alfapt(t) = alfap;
alfayt(t) = alfay;
if eychar>0;
anspirits(t)=alfay;
end
if eychar<0;
anspirits(t)=1-alfay;
end
end
autocory = corrcoef(y,ylagt);
autocorp = corrcoef(p,plagt);
coroutputanimal = corr(y,anspirits);
```

```
%% mean, median, max, min, standard deviation, kurtosis
Kurt = kurtosis(y);
%% jarque-bera test
[jb,pvalue,jbstat] = jbtest(y,0.05);
```

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