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To each his own: the weighting schemes of monetary policy

A DSGE scenario analysis of the Euro Area and its Members

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Abstract

In this thesis, the role of different weighting schemes applied by a central bank to the members of a currency union in the conduction of monetary policy is analyzed. The analysis is conducted by embedding the coefficients of a Taylor rule, estimated by GMM on Euro Area data, in the two–country, open economy DSGE model developed in Erceg and Lindé (2013). Subsequently the simulated impulse response functions to two types of shocks, one that hits the whole currency union and one that hits only one member of the union, are analyzed for each weighting scheme (or scenario, which indicates each different combination of weights within the Taylor rule). The main results outline that the reactions of the members to a shock that hits the whole union are largely insensitive to the weighting scheme applied by the central bank, whereas, when a shock only hits one member and then propagates, the weighting scheme plays an important role in determining the stabilization process.

Keywords: New Keynesian DSGE, Taylor Rule, open economy, policy weights, currency union

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1 Introduction

The European Central Bank (ECB) operates in an unique, interesting framework that aims at guaranteeing price stability for all the members of the currency union (CU henceforth) over which it has monetary sovereignty, whilst allowing an independent conduct of fiscal policy, that is the instrument used to adjust to the decisions made by the ECB. Clearly, the single members of the union are given an instrument to autonomously adjust to the central monetary policy because the latter focuses on price stability in the whole Euro Area (i.e. the Countries that have adopted the Euro, EA henceforth), as opposed to stabilizing every single economy, as it would be an impossible task to undertake. This setting is often analyzed through the popular New Keynesian DSGE models - which are also employed, in some measure, by Central Banks (henceforth CBs) – in papers such as Christiano, Eichenbaum, and Evans (2005), Fagan, Henry, and Mestre (2005), Monacelli and Galí (2005) among others.

These studies produce models that are able, to different degrees, to match the rigidities empirically observed by the researchers; whereas all have in common their focus on the Euro Area , some of them focus on the aggregate EA (e.g. Fagan, Henry, and Mestre (2005)) whereas others (Monacelli and Galí (2005), Dieppe, Gonzalez Pandiella, and Willman (2012))) also include an open economy aspect, to describe both the currency union (CU henceforth) and its single members. The latter category necessarily addresses the issue of the weights of each country in the CU: since the ECB operates by considering aggregate variables at the union level, the models must describe how these variables are aggregated. In other words, the country–specific macroeconomic aggregates are combined according to a measure of each country's size in the union, usually a measure of their actual population (as a percentage of the total CU's) or their percentage share of aggregte GDP: consequently, these weights determine the conduction of monetary policy as usually described in DSGE models through simple reaction functions or loss functions.

This thesis, building on the model presented in Erceg and Lindé (2013), analyzes a simulated discrepancy between the actual economic weight of the CU members – as measured by their percentage share of GDP on the union total – and the weight that the ECB imposes when conducting monetary policy (represented by each Country's variables' weight in the aggregation of union–wide indicators). In other words, this work aims at analyzing the consequences of the CB giving different importance (i.e. weights) in the conduction of monetary policy to the member states than their actual one; the question, for clarity, could be phrased as "What are the consequences for the member states and for the whole CU if the ECB chooses to give more importance to stabilizing some economies rather than others?".

The relevance of this research question is twofold. Economic, as it examines different possible reaction scenarios of a CB to shocks in a CU, and political, as it suggests different weighting schemes within a supranational organization (with sovereignty on monetary policy) that are not necessarily rooted in purely economic considerations. In fact, in most applications of DSGE models to the Euro Area context, the weights of the member states in the eyes of the ECB are assumed to be either their economic ones or their demographic ones: the contemplation of different weighting scenarios could be a useful insight on the conduction of monetary policy in a CU. Turning to the political relevance, there exists some literature that focuses on the optimal distribution of voting rights within the ECB's Governing Council: one view that is presented is that a more equal representation would result in more political stability in the union[1]. This political concern is indeed relevant, as political instability could pose a threat to the whole currency union and hinder the economic stability of its members as well. The link with political instability is more relevant than ever as, for instance, the recent conduct of monetary policy of the ECB is being criticized by the German opinion based on the perception that it has focused on the stabilization of southern european economies.[2]

The attempt to answer this question follows two steps: firstly, a simple Taylor rule is estimated from EA data, in order to obtain a representation of the actual conduction of monetary policy by the ECB. The rule is estimated with the Generalized Method of Moments (GMM henceforth), a standard instrument in the literature. Secondly, the estimated parameters are embedded in the model used for the analysis (a two–country open economy DSGE model) and the responses to exogenous shocks are simulated in five different scenarios, that differ among themselves for the weight that each member of the CU has in the Taylor rule that describes the behaviour of the ECB in the model.

The rest of the thesis develops as follows: Section 2 provides a brief review of the relevant

[1]Some examples are Berger (2006), Berger and De Haan (2002), Gros and Hefeker (2002) and Berger and Mueller (2007). This branch of literature focuses on finding the optimal weights of each member of the union, and hence will not be discussed in this thesis as the objective of this work is not to find the optimal weighting scheme but rather to analyze the difference between many of them.

[2]From Jones and Wagstyl (2016).

literature, Section 3 describes the data and the empirical estimation of the policy rule, Section 4 describes the model, Section 5 describes the methodology employed to obtain the results and the different scenarios, Section 6 presents the results of the simulations, Section 7 discusses the results, Section 8 outlines some of the limits of this work and, finally, Section 9 concludes.

2 Literature Review

2.1 A brief review of Taylor Rule related literature

Ever since John Taylor, in his seminal 1993 paper (Taylor (1993)), introduced the famous policy rule that links the policy rate, i_t, to inflation and the output gap, a large body of literature has employed different specifications and estimation techniques to describe and evaluate the conduction of monetary policy in a number of different instances. The history of the Taylor Rule, therefore, is one of continuous refinements. Among these, a very prominent example of an empirical modelling of the policy rate as a response to relevant macroeconomic variables is Clarida, Galí, and Gertler (2000): the authors introduced a specification and estimation method of the Taylor rule that have now become standard in the vast body of literature. In fact, they introduced a forward–looking aspect to the rule, together with a smoothing coefficient that describes the gradual adjustment of policy rates as opposed to the instantaneous adjustment implied by its original formulation. Their estimation was conducted by the Generalized Method of Moments , which enables taking into account the wider information set that policymakers have at their disposal at the time of taking a decision on the short–term interest rate. Namely, because the elements considered by the central banker are a wider array as compared to only inflation, the short term rate and output gap, but because at the same time it is not viable to specify all of them explicitely, GMM allows to acknowledge the vastity of the actual information set while producing a fairly simple and reliable estimate.

The aforementioned papers focused on US data, but there have been many other estimations of Taylor–type policy rules for the EA as well. There is a wide variety of estimations that differ in the time periods analyzed, in the measures of the target variables (i.e. inflation and output gap), in the estimation methods and augmentations.

Among the latters we find, for example, Sauer and Sturm (2007), Ullrich (2003), Faust, Rogers, and Wright (2001). All these papers, despite their differences, conclude that it is fundamental to include the forward–looking perspective introduced by Clarida et al., for the transmission of monetary policy happens with delay and hence the policymakers must be forward looking in their decisions. As previously mentioned, a wide amount of literature has analyzed different aspects of what now is the standard formulation of the rule, branching out in different yet intertwined directions.

Following one of the aforementioned directions, a part of the literature has focused on the gradual adjustment of interest rates: one prominent example of such research is, for example, Rudebusch (2002). In his paper, he claims that there is no evidence of interest rate smoothing behavior by the CB at quarterly frequency –although the same cannot be said for monthly estimates–, and that, therefore, the observed relevance of the smoothing parameter could be instead caused by responses to other persistent shocks. Another interesting example is that of Gerlach-Kristen (2003): the author, instead of relying on a smoothing coefficient, argues that the observed unit–root behavior of the policy rate must be taken into account and hence estimates a policy rule following a cointegration approach. In accordance with Rudebusch (2002), the papers rejects the smoothing behavior of the CB in favour of the estimation of a cointegrating relationship; it must be noted, though, that the quarterly data utilized are for a great part a fictitious EA aggregate, generated from the single countries' time series. An important feature to keep in mind is that neither Rudebusch, nor Gerlach–Kristen, questions the importance of the forward looking aspect of the policymakers, on the contrary they both highlight it. As interesting as these examples may be, there is also great support for the gradual adjustment of policy rates by the CB, for example in Castelnuovo (2007). His study employs different specifications of the Taylor rule and tests the relevance of the smoothing coefficient, considering both contemporaneous and forward–looking rules as well as different augmentations.

A second, extensive, "branch" of the literature accepts instead the baseline specification proposed by Clarida, Galí, and Gertler (2000) and hence the forward–looking approach, but focuses mostly on augmenting the rule with different, relevant economic variables and employs different measures of output gap. Examples include, among others, Gerdesmeier and Roffia (2003) and Fourçans and Vranceanu (2004). Both these studies, in fact, estimate multiple Taylor–type rules using different measures of economic activity (e.g. industrial production growth and deviation from trend, real GDP growth) augmenting them by including the growth rate of the M3 money aggregate (or its deviation from trend growth) and measures of the Euro–Dollar exchange rate. Let us turn to the former study: Gerdesmeier and Roffia (2003) employs a fictitious Euro Area, built by aggregating the single countries' time series. The authors apply different filtering techniques (linear detrending, quadratic detrending, HP filter) to both real GDP and industrial production in order to construct measures of output gap. Inflation is instead measured by either annualized HICP growth, by the GDP deflator (for a measure of headline inflation), or by the annualized growth of HICP net of energy prices and unprocessed food (for a measure of core inflation). The Taylor rule is estimated by both OLS and GMM, and it is augmented with the deviation of M3 from its growth trend and a measure of asset prices. The authors conclude that the interest smoothing term is always positive and significant, as well as the deviation of M3 from its growth and the asset prices variation measure. It must be noted, however, that the influence of the monetary aggregate might be wrongly represented. In fact, as the dataset was constructed by aggregating different national variables, the great importance of M3 could stem from the focus on monetary aggregates that the Bundesbank had, compared to to other national CBs (much of the early literature on Taylor rules in the EA uses the Bundesbank as a proxy for the ECB before 1999). M3's importance is not confirmed, instead, by the latter study. As to what the two have in common, Fourçans and Vranceanu (2004), estimate (again both by OLS and GMM) forward–looking specifications of the Taylor rule, augmented with the foreign exchange rate (Euro/Dollar), with M3 money aggregate growth and a measure of asset prices, much like the former study. The main differences in the estimation concern firstly the data sample (which is composed of actual data for the EA spanning the period 1999:04–2003:10), and secondly the utilization of different forward horizons for the expected inflation and the output gap; the latter is measured by monthly industrial production growth. The authors find the augmentation of the rule with the foreign exchange rate to be a significant one, but they reject the hypothesis of the importance of a mechanical response to the growth rate of money. They also recognise that six months might not be the most appropriate lead to be included for inflation, although the length of their sample constrained them to this decision.

Lastly, Surico (2003b), Section I, provides a useful short review of different studies[3] that find the inclusion of a monetary aggregate in the policy rule to be nonsignificant.

[3] Like Galí (2002).

Nevertheless, this does not necessarily imply that the monetary aggregate does not yield useful information for the conduction of monetary policy: Castro (2008), for example, includes it in the vector of instruments used in the GMM estimation of a linear policy reaction function.

In wake of the financial crisis of 2008, the attention of the literature has shifted towards whether a CB, when taking policy decision, should consider financial stability an additional target. Consequently, a consistent part of the research has focused on augmenting the Taylor rule with different types of financial variables, in line with the view expressed, among others, by Woodford (2012). The latter states that financial stability should indeed be a concern for policymakers, advocating the benefits of taking into account the effects of changes in the short–term interest rate on the probability of the occurrence of a financial crisis. Note that there is no widespread consensus on whether a CB should explicitly include financial stability among its targets: prominent economists such as Bernanke and Svensson, in fact, support the view that monetary policy cannot efficiently address the issue, see Svensson (2012) for a cost–benefit analysis of leaning against the wind, for example, which should be dealt with by macroprudential policy.

Among the previously mentioned augmentations of the Taylor rule, there are the ones considering exchange rates – e.g. Svensson (2000) – many of which, though, conclude that such augmentations would not be significant or an appropriate target for a CB. Other researchers instead focused on asset prices, credit and spread augmentations: please refer to Käfer (2014) for a comprehensive review of Taylor rules and financial stability.

Finally, it should be noted that the research described so far refers mostly to the estimation of linear policy rules, whereas there exists a growing body of literature that lifts the linearity assumption[4].

A linear estimation, in fact, assumes implicitely that the CB reacts in the same way to both positive and negative deviations of inflation and output gap from the intended target.

Allowing nonlinearity into the modelling of policy responses, conversely, solves contemporaneously this issue as well as that of observed unit–root behavior of policy

[4] Recall that the previously mentioned study of Gerlach–Kristen aimed at modelling the observed nonlinearity through a cointegration equation.

rates. Examples of nonlinear policy rules estimation include Bunzel and Enders (2010), Castro (2008) and Surico (2003a): the first two studies employ different specifications of Threshold Autoregressive Models (TAR), whereas Surico (2003a) lifts the symmetric reaction assumption by introducing squared deviations of inflation from the intended target and output gap, together with an interaction term between the two. All the papers find support for the hypothesis that the CB's reaction is state–dependent. For instance, Bunzel and Enders find that the FED reacts more aggressively if inflation is above the estimated threshold value and output gap is negative, while Surico finds greater responses to output gap contractions compared to expansions of the same magnitude and Castro (2008) finds that the ECB reacts to inflation when it is above 2.5% and to output gap only when inflation is stable below that threshold.

It must be noted that, given that the purpose of this paper is not the estimation of a policy reaction function *per se*, but rather providing an analysis of the different weights of EA members and their interaction with monetary policy decisions, it will suffice to consider a simple, linear framework even though nonlinear modelling and augmentations that consider the financial markets as well undoubtedly have more attractive features.

2.2 A brief review of DSGE models evolution

The aim of this analysis is to observe the impact of the weight assigned to a member of a currency union (CU) relative to the union's total, on both the individual members' and the union's responses to different kinds of shocks. This question is studied within a New Keynesian DSGE framework: this kind of model is often employed as an instrument to analyze the different forces that act within an economy by policymakers. The following shortly summarizes the development of such framework[5].

One of the early, most prominent examples of a DSGE model is certainly the RBC model developed by Kydland and Prescott (1982). In their model a representative, infinitely lived agent (or household) decides its levels of consumption and working hours (or leisure) in order to maximize his utility. Households provide labor to firms – which use labor and capital as inputs – that produce and sell final goods: all of the markets in which these intractions happen are perfectly competitive. In other words goods, labor

[5] This review only aims at providing the reader with some context in which to position the model that will be described later. For a more thorough review of the literature on DSGE models, the reader is invited to refer to Christiano, Eichenbaum, and Trabandt (2017) and the works mentioned therein.

and assets are traded in frictionless markets. Kydland and Prescott claim, in their study, that the observed fluctuations in the aggregate economic variables are responses to exogenous technological shocks: whereas their work has been a great advancement in the grounds of modelling the interaction between economic forces, it falls short of explaining some properties of aggregate variables. Namely, the frictionless design of markets made it so that the behavior of aggregate variables failed to match many characteristics observed from empirical studies and gave no role to monetary policy, contradicting the observed reality.

Building on the aforementioned framework, the further development of DSGE models has produced prominent studies such as Christiano, Eichenbaum, and Evans (2005) (CEE henceforth). In their work, the authors try to give an explaination to the observed persistence in aggregate quantities and inertial behavior of inflation via a DSGE model: in order to do so, they first estimate the response of U.S. aggregate variables to a monetary policy shock. The results of their empirical analysis outline a number of properties of the data that challenge the flex–price setting proposed by the early RBC models. Namely, they observe hump shaped responses of inflation, output, consumption and investment and a response of real variables (real wage, real profit) to a monetary policy shock: these empirical findings are in open contrast with the implications of the RBC model proposed by Kydland and Prescott. To match the observed behavior of aggregate macroeconomic variables, CEE upgrade the previosly mentioned model with a number of features. First and foremost, they implement sticky prices and sticky wages à la Calvo, i.e. assigning to each household and firm a finite probability of being able to reoptimize their price/wage for each period (note that the probability of reoptimization is independent of its past realizations). They also allow for variable capital utilization, investment adjustment costs and consumption habit formation, all of which help in generating hump–shaped responses to policy shocks, as observed from the VAR evidence.

Another excellent example of a New Keynesian DSGE model is Smets and Wouters (2003), where the authors estimate a DSGE model for the Euro Area using Bayesian estimation techniques and increasing the number of exogenous shocks considered. As the framework is rather close to the one described above, for a more detailed tractation the reader is encouraged to refer to the publication.

The models described so far all consider a closed economy dimension: Adolfson et al. (2007) update the CEE model by adding an open economy dimension. Their estimation is based on EA data (more specifically, the Area Wide Model dataset) and it adds an element of novelty in that there are now consuption and investment goods that are imported from the foreign economy: these goods, together with the domestic ones, enter bundles of consumption and investment goods proportionally to each economy's openness to trade. Within that same framework, Erceg and Lindé (2013) and Blanchard, Erceg, and Lindé (2016) analyze fiscal policy in a currency union: they employ a two–country open economy model, but the different countries are now part of a currency union. Namely monetary policy is now conducted by a CB that focuses on the stabilization of CU aggregates[6], whereas the single members are free to adapt to the CB's decisions through their fiscal policy. A simpler version of this model (for expositional purposes) is outlined in Section 4.

3. The Taylor Rule and its empirical Estimation

3.1 The Taylor Rule

Section 2.1 outlined how the Taylor rule and its estimation have been treated in the literature: indeed, it has been widely used to describe and evaluate monetary policy conduction of a number of central banks. Its attractivenes comes not only from its simplicity and intuitiveness, but also from its fairly good performance when compared to the minimization of a theoretical quadratic loss function of the policymaker[7].

As a matter of fact, simple rules of this kind are frequently used in DSGE models (due to the characteristics just described) to describe the policymaker's behaviour[8]; hence its attractiveness in this paper's framework. There are clearly some advantages and disadvantages in employing a simple reaction function: this Section will present the Taylor rule as utilized in the analysis and its estimation from the data. Its purpose is to clarify the reasons behind the choice of this framework, while keeping in mind the variety of available options.

[6]Among the studies focused on open economy DSGE models, Monacelli and Galí (2005) show that it is optimal for the CB to target aggregate variables.

[7]See, for example, Peersman and Smets (1999).

[8]The DSGE model employed in this analysis (Erceg and Lindé (2013)) does, for example.

The following rule is the one proposed by Taylor (1993) to describe the behavior of the FED over the period 1987–1992:

$$i_t = \pi_t + 0.5x_t + 0.5(\pi_t - 2) + 2$$

Where: i_t is the Federal Funds Rate, π_t is the inflation rate and x_t is the output gap measured by the percentage deviation of real GDP from its trend. Note that both the inflation target (π^*) and the equilibrium real rate (r^*) are set to 2 (i.e. 2%)

The rule can be rearranged, in more general terms, as follows:

$$i_t = (r^* - 0.5\pi^*) + 1.5\pi_t + 0.5x_t$$

It is easier to notice an important property of the rule, after having rearranged it: the inflation coefficient is greater than one, which is now commonly referred to as the "Taylor principle". It states that, in the long run, the nominal short–term rate must respond more than one–to–one to movements in inflation, effectively stabiizing inflation around the declared target[9].

As previously mentioned, this type of rule is quite restrictive: it does not take into account the different economic variables that a CB pays attention to when conducting monetary policy (other than inflation and a general measure of economic activity), it assumes that CBs respond to contemporaneous values of the aforementioned variables rather than expected ones and it assumes instantaneous adjustment of the policy instrument. Several authors (Clarida, Galí, and Gertler (2000), Gerdesmeier and Roffia (2003), Peersman and Smets (1999), Gerlach and Schnabel (2000), Qin and Enders (2008) among others) have recognised the importance of including a forward looking aspect in the empirical estimation[10], together with the necessity of allowing for gradual adjustment of the policy instrument. In this paper, the estimated empirical rule will take into account all these aspects; the following is, in fact, a rule of the type introduced by Clarida, Galí, and Gertler (2000).

[9]Clarida, Galí, and Gertler (2000) mention, in their work, that a response to movements in inflation smaller than (or equal to) unity will be destabilizing for the economy, or accomodative with respect to inflation.

[10]The ECB as well, in their monetary policy explainer (ECB (2011)), notes that "...monetary policy nust be forward–looking and pre–emptive".

$$i_t = (1-\rho)(R + \gamma_\pi(E_t[\pi_{t+k}|\Omega_t] - \pi^*) + \gamma_x E_t[x_{t+j}|\Omega_t]) + \rho i_{t-1} + \epsilon_t \tag{1}$$

Where i_t is the short–term interest rate, $E_t[\pi_{t+k}|\Omega_t]$ and $E_t[x_{t+j}|\Omega_t]$ are respectively the expected values of inflation and output gap k and j periods ahead, given the information set Ω available at time t. The constant R can be interpreted as the equilibrium nominal rate, i^* or $r^* + \pi^*$, when the output gap is closed and inflation is on target, π^*. The assumption of rational expectations is conveyed by the expectations operator E_t: the ECB is assumed to perfectly forecast future values of inflation and the output gap. In practice, this means that when estimating the policy reaction function, the expectation terms will be substituted by the actual realizations in the future of the variables.

Please note that the importance of the aforementioned terms is twofold: on one – more theorical – hand they allow the assumption of rational expectations and capture the extremely important time lag in the transmission of monetary policy. In other words, due to observed nominal rigidities, the economy does not immediately adjust to changes in monetary policy, hence policymakers must "look forward" and take this delay into account when making policy decisions. On the other hand, introducing the expected future value of the variables of interest *conditional on the information set available at time t* (Ω_t) allows to take into consideration the fact that not all information available to policymakers enters the rule. Namely, CBs have at their disposal a wide set of variables which they monitor, but they do not necessarily react mechanically to movements in these variables (meaning that they would not appear in a reaction function).

As also mentioned in Section 2, a wide share of the literature on Taylor rules has considered augmenting the reaction function with an array of macroeconomic and financial variables: nonetheless, there is no widespread consensus on the most appropriate augmentation. Given this fact, as well as the restriction imposed by the size of the dataset utilized for the empirical estimation (that will be described shortly), the specification presented above will be the one utilized for the estimation of the parameters.

3.2 The data

The dataset used for the empirical estimation of the coefficients of the rule presented above was built with particular attention to the ECB's explainer (ECB (2011)). Most variables were downloaded from Eurostat, with the exception of M3 money aggregate's annualized growth rate, which was retrieved from the ECB Statistical Data Warehouse. The variables downloaded from the mentioned sources are the following: real GDP, measured in chain–linked volumes (namq_10_gdp, from Eurostat), annualized HICP inflation[11] (prc_hicp_manr, from Eurostat), EONIA and three–months ahead EURIBOR rates (irt_st_m, from Eurostat), ten–year EMU convergence criterion rates (irt_lt_mcby_m, from Eurostat), industrial production (sts_inpr_m, from Eurostat) and M3 annualized money growth (BSI.M.U2.Y.V.M30.X.I.U2.2300.Z01.A, from the ECB's Statistical Data Warehouse).

All the above data were downloaded for the period 1999:01–2007:12 (January 1999 to December 2007, at monthly frequency), since the estimation of the monetary policy conduct for the scope of this analysis is focused on normal times (i.e. before unconventional monetary policy measures were put into action because of the most recent crisis). Thus, the number of available observations is 108 for each variable, with the exception of GDP that is only available at quarterly frequency: in order to have a more granular time series, the variable was linearly interpolated to obtain monthly observations. Note that linear interpolation was chosen as a conservative approach in order to avoid the generation of excess fictitious variance: the assumption of little variability of real GDP on a month–to–month basis seemed a reasonable one, against the danger of obtaining biased coefficients due to excessively generated variance.

3.2.1 Generation of variables

The policy rule described by Equation (1) models the response of interest rate (i_t) to annualized HICP inflation (π_t) and output gap (x_t): whilst the first two variables need not be generated (i_t is proxied by the three–month EURIBOR rate, whereas HICP inflation is available from Eurostat) the latter does. Output gap was generated, following the literature, as the percentage deviation of real GDP (or industrial production) from

[11] Even though much of the literature also considers a measure of core inflation, the focus is only on full HICP inflation since "The ECB. . . does not consider core inflation to be an appropriate yardstick for price stability in the Euro Area", ECB (2011), p. 65.

trend: both real GDP (y_t) and industrial production (IP_t) were detrended by using the HP filter. Namely,

$$x_t = 100 * K^{cyc}$$

Where: $K^{cyc} \in (y_t^{cyc}, IP_t^{cyc})$, y_t^{cyc} is the cyclical component of HP–filtered $log(y_t)$ and IP_t^{cyc} is the cyclical component of $log(IP_t)$.

This definition of output gap has been widely employed in the literature of empirical estimations of Taylor rules,[12] as it provides a good solution to the issue inherent to the formal definition of output gap.

In fact, output gap is defined as the deviation of output from its potential level, which is the level of output that would prevail if prices and wages were completely flexible: clearly, the latter is completely dependent on the model used to describe the economy in question. In order to avoid suffering model misspecification biases, and in order not to tie the empirical estimation to the specification of the model, the percentage deviation from trend was chosen as a measure of economic activity.

3.2.2 Data visualization

The following graph plots the variables used for the estimation of the policy rule.

[12]See, among others, Gerdesmeier and Roffia (2003).

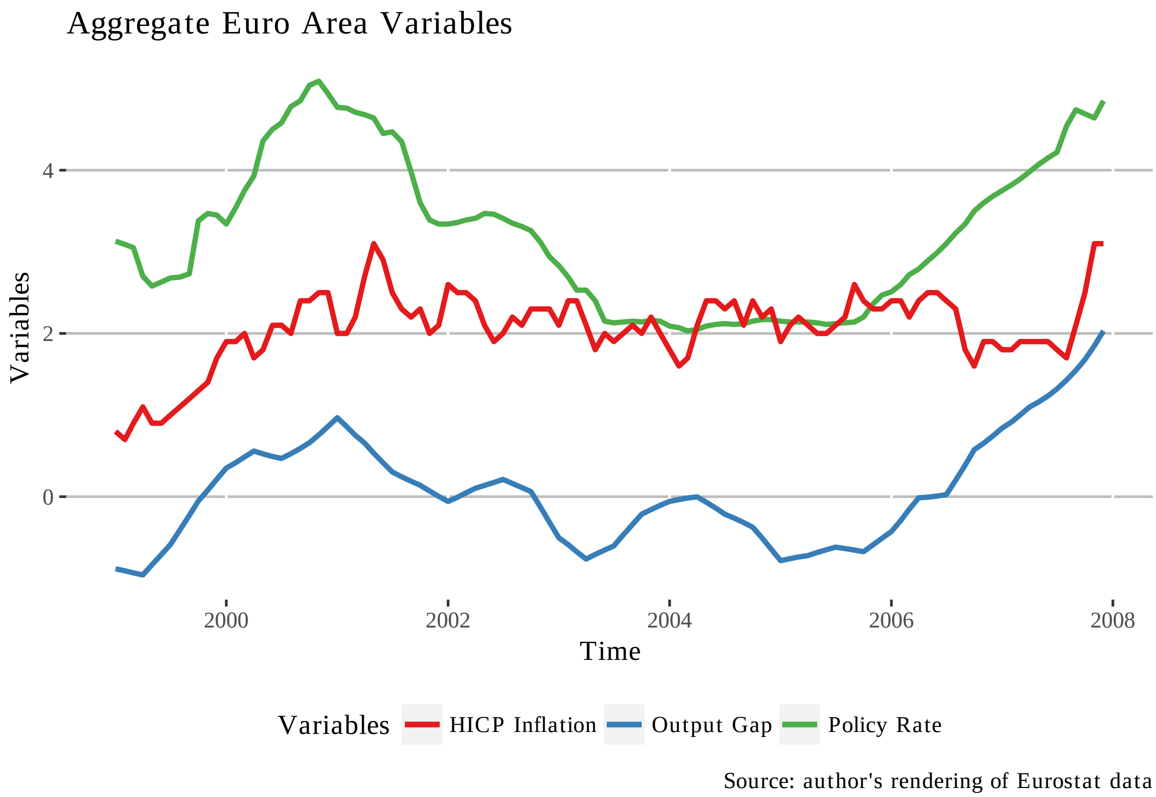

Figure 1: Aggregate EA variables

It is clear that the ECB has been able to meet its intended price stability target: after an initial adjustment period (1999), during which it had just started operating, the HICP inflation series is clearly stable around 2%. Please note that ECB (2011) provides the quantitative definition of price stability: "Price stability shall be defined as a year–on–year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below, but close to 2%. Price stability is to be maintained over the medium term". The aforementioned document also provides a description of the evolution of the policy rate in Section 5, the reader is encouraged to refer to it to have a better understanding of the dynamics of interest rate. Yearly increase in HICP inflation, although certainly crucial, is not the only perspective from which price stability and threats to it are assessed: the ECB relies on a well–known "two–pillars" approach that focuses on real economic activity in the short term and on monetary analysis in the medium–long term[13].

[13]Refer to ECB (2011), Section 3.5 for a more detailed discussion.

This approach is utilized so that no relevant information is lost when assessing risks to price stability and deciding the most appropriate course of action: it is bearing in mind this important principle that the specification of a reaction function described in (1) was chosen. In fact, keeping in mind that the literature has been unable to undisputedly support the inclusion of a monetary growth term in the Taylor rule, and given the focus of price stability as given in the previous quantitative definition, the only explicit responses of interest rate have been set to be those to inflation deviations from target and to output deviation from trend.

3.3 Empirical estimation

The reader is invited to refer to Appendix A for a more detailed description of the GMM estimator.

3.3.1 Empirical estimation of the Taylor Rule.

The previous Sections have outlined the grounds on which GMM was chosen as the instrument for the empirical estimation of the Taylor rule and why the specification in (1) was deemed the most appropriate. The estimation was conducted on the previously presented data, from which the following set of instruments was used:

- Lags 1, 3 and 6 of HICP inflation;
- Lags 1, 3 and 6 of M3 aggregate money growth;
- Lags 1, 3 and 6 of output gap;
- Lags 1, 3 and 6 of 10–year EMU criterion long term convergence rates;

The overidentified system is estimated on the basis of moment conditions that are derived from the theoretical model employed[14], in this case we follow Clarida, Galí, and Gertler (2000) for the specification of the conditions. Namely, (1) implies the following set of moment conditions:

$$E[\ (i_t - (1-\rho)(R + \gamma_\pi(E_t[\pi_{t+k}|\Omega_t] - \pi^*) + \gamma_x E_t[x_{t+j}|\Omega_t]) - \rho i_{t-1} + \epsilon_t)z_t] = 0$$

[14]Please refer to Appendix A for a discussion of the moment conditions' role in the estimation.

Where $z_t = (\pi_{t-1}, \pi_{t-3}, \pi_{t-6}, g^{M3}_{t-1}, g^{M3}_{t-3}, g^{M3}_{t-6}, x_{t-1}, x_{t-3}, x_{t-6}, i^{LT}_{t-1}, i^{LT}_{t-3}, i^{LT}_{t-6})'$

The above moment conditions only require the set of instruments to be uncorrelated with the error term: it is standard in the literature to include lagged values of the variables that appear in the Taylor rule as instruments (intuitively, the past values of inflation and output gap can help in predicting their future ones), that satisfy this restriction (as will be shown later, Hansen's J–test accepts the instruments as valid). The long term convergence criterion rates were chosen following both Clarida, Galí, and Gertler (2000) and the intuition provided by Gerlach-Kristen (2003), who suggests that long term rates yield useful information on agents' expectations of future inflation and, to some extent, of near–term monetary policy. Lastly, a measure of monetary growth was included in the instruments according to the monetary analysis pillar outlined in ECB (2011). As previously mentioned, the literature has not expressed a consensus on whether measures of monetary aggregates are a significant determinant of the evolution of policy rates (i.e. whether it should be included in the Taylor rule as an explanatory variable), hence the more appropriate course of action seemed to be its inclusion in the instruments vector[15].

The forward horizons of the expected future values of inflation and output gap (i.e. k and j in (1)) were chosen to be, respectively, 12 and 3. The selection was done using both AIC and SBIC as criteria. The results of the estimation are the following[16] :

[15]Note that Clarida, Galí, and Gertler (2000) and Castro (2008), among others, include some measure of monetary activity in their instruments as well.

[16]Coefficients' standar errors are shown in brackets.

	GMM estimation results
ρ	0.87^{***}
	(0.03)
γ_π	1.19^{*}
	(0.59)
γ_x	1.90^{***}
	(0.37)
R	3.23^{***}
	(0.12)
Criterion function	7399.15
Num. obs.	102

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 1: Estimated Coefficients

Hansen's J–test of overidentifying restrictions is unable to reject the null hypothesis $H_0 : E[g(\theta, w_t)] = 0$, hence we accept the moment conditions to be correctly specified, which implies that the chosen instruments comply with the orthogonality conditions.

The above table shows that the ECB has indeed been operating to stabilize inflation: in fact the Taylor principle is respected, as the point estimate for γ_x is positive and greater than unity (also recall from Figure 1 that inflation has indeed been stable around 2%). The estimation also underlines a fair degree of interest rate smoothing and a responsive attitude towards fluctuations in the output gap.

3.3.4 Sensitivity of the empirical estimation

This section presents two different robustness checks on the estimated rule.

- *Sensitivity to a different measure of economic activity*

The measure of economic activity chosen to enter the Taylor rule is output gap, as described in Section 3.2.1: the same estimation was conducted using instead the industrial production gap. In fact, it is standard in the literature to also consider industrial production as a candidate for proxying real economic activity; moreover, note that the time series is available at the same frequency as inflation and interest rate (i.e. monthly), so it does not need to be subject to interpolation. The forward horizons were both chosen to be 12, as indicated by the AIC and SBIC criteria. The results of the estimation are the following:

	Output Gap	Industrial Production Gap
ρ	0.87^{***}	0.81^{***}
	(0.03)	(0.08)
γ_π	1.19^{*}	1.67^{*}
	(0.59)	(0.77)
γ_x	1.90^{***}	0.64^{*}
	(0.37)	(0.32)
R	3.23^{***}	2.30^{***}
	(0.12)	(0.25)
Criterion function	7399.15	8127.19
Num. obs.	102	102

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 2: Point Estimates comparison, Output gap vs. Industrial Production gap

As shown above, the estimations are robust from a qualitative point of view: the degree of interest rate smoothing is similar, the Taylor principle is respected in both cases, all estimates are significant at least at the 95% confidence level. On the other hand, the point estimates are somewhat different for γ_π, although the most striking difference is the value of γ_x: its value, in fact, drops below unity when industrial production is used as a proxy for economic activity. A feasible explanation for this occurrence could be found in the great difference between the two series' variabilities: as shown in the graph below, the industrial production gap is much more variable than the output gap, hence the response to fluctuations in the former are estimated to be much smaller by the model.

Please note that both the SBIC and Hansen's J–test indicate the estimation using output gap as the best choice between the two (i.e. the J–test's statistics is is greater for the industrial production gap case, meaning that there is a greater possibility of rejecting the null. Note, though, that the orthogonality condition are fulfilled in this case as well.).

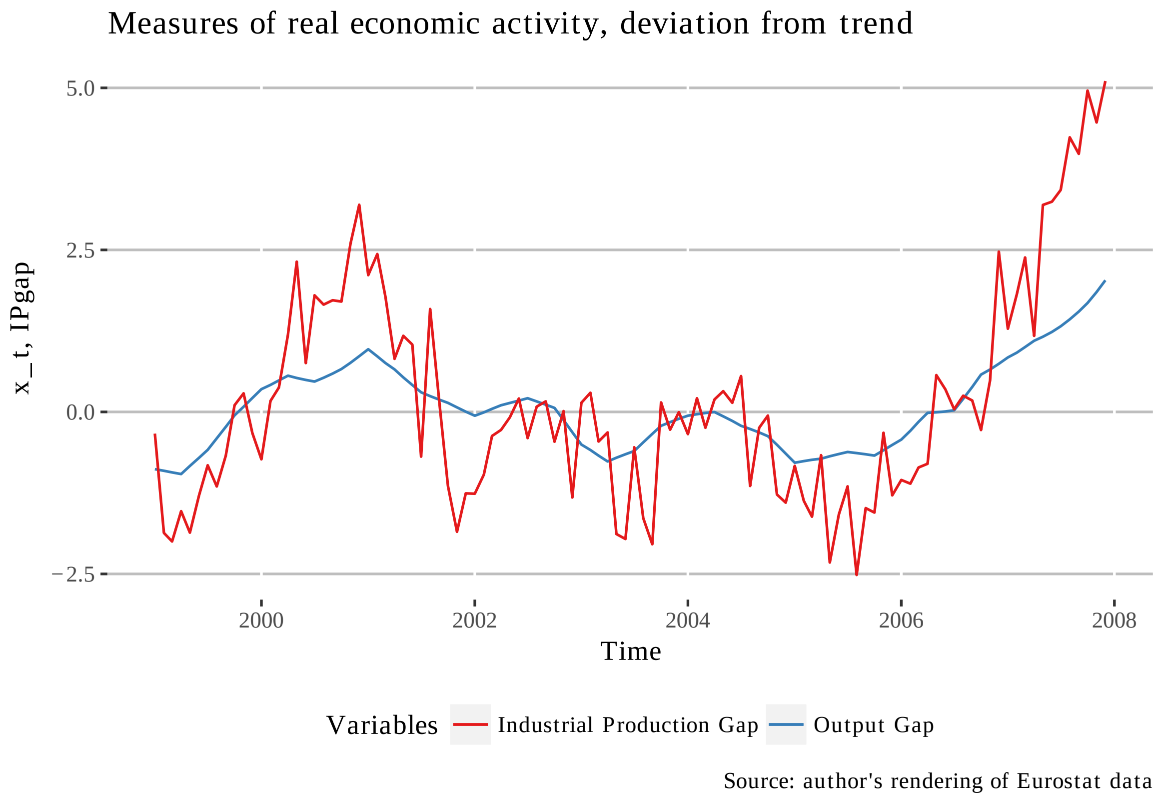

Figure 2: Output gap and Industrial Production gap

- *Sensitivity to the inclusion of Slovenia*

Slovenia entered the European Union, and adopted the single currency, in 2007: therefore ,the data concerning it are absent from the aggregation up until then. For the data sample described previously, this means that Slovenia is present only for the last twelve periods. Excluding Slovenia as a robustness check, therefore, is needed to ensure that the significance, direction and magnitude of the estimated coefficients is not greatly driven by its inclusion, but that it is rather caused by a true relationship among variables across the whole sample. The following table compares the GMM estimation using Eurostat's aggregates to one conducted using manual aggregation[17] of each EA country's variables except for Slovenia. Hence, the regression relative to the Eurostat–aggregated EA series includes Slovenia starting from 2007. The regression relative to manual aggregation of the EA series does not include Slovenia. Clearly though, this implies that besides the

[17] The reader should acknowledge that Eurostat does not disclose the nature of models used in order to create EA aggregates. As to the manual aggregation, it was done on the basis of single countries' time series and publicly available weights for each Country both provided by Eurostat.

exclusion of Slovenia from the aggregate, the two series differ as to the technique of aggregation of single countries' time series.

	Eurostat Aggregation	Manual Aggregation
ρ	0.87^{***}	0.90^{***}
	(0.03)	(0.03)
γ_π	1.19^{*}	1.61^{*}
	(0.59)	(0.81)
γ_x	1.90^{***}	1.81^{**}
	(0.37)	(0.63)
R	3.23^{***}	2.96^{***}
	(0.12)	(0.26)
Criterion function	7399.15	14624.19
Num. obs.	102	102

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 3: Eurostat vs. manual aggregation, GMM estimates

As the table above shows, the estimation is pretty robust to the exclusion of Slovenia from the aggregation. The notable difference in the point estimate for γ_π is due to the differences between the manually aggreated HICP inflation series and the one produced by Eurostat. In fact, due to data scarcity issues and to the confidentiality of the model used to produce the Eurostat aggregate, it was impossible to perfectly reproduce the latter.

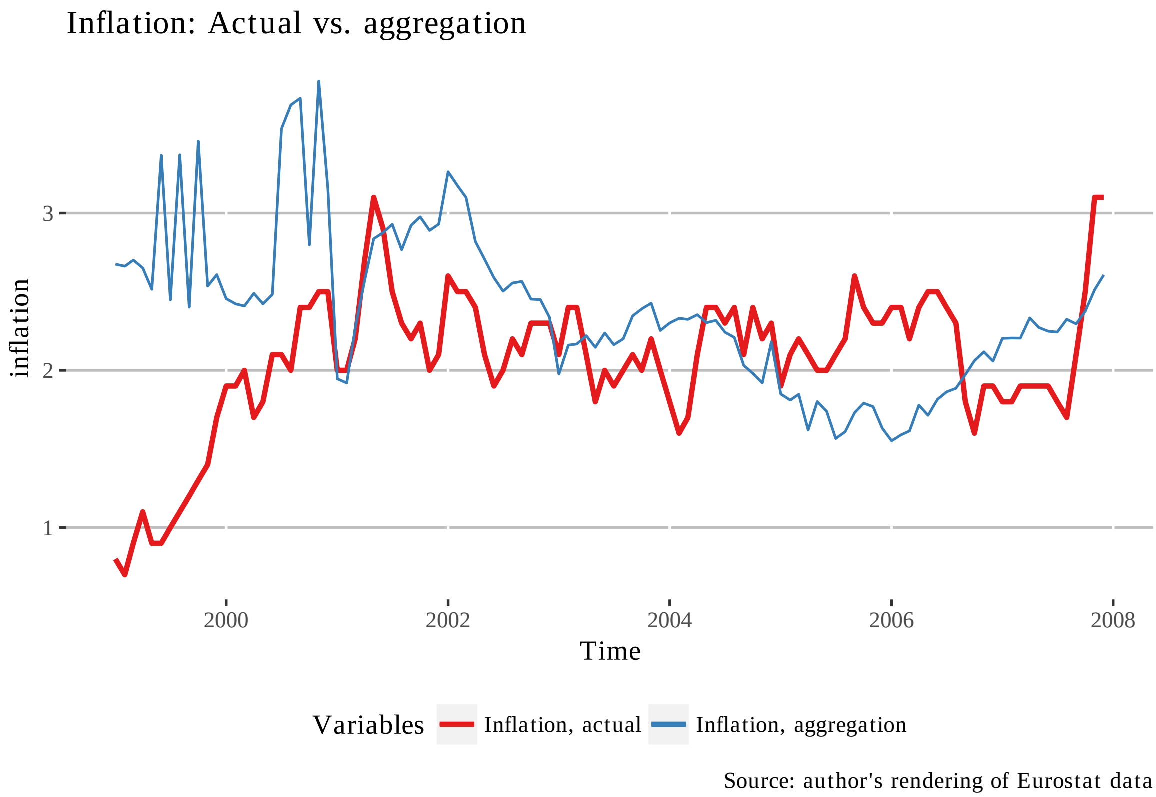

Figure 3: Manual vs. Eurostat aggregate inflation

Please note that in the above representation the manually aggregated series, for the first two years of the sample, displays a greatly different behavior compared to the Eurostat one. This stems from a data scarcity issue: inflation series for the single countries often start from 2001 or 2002, hence the missing observations at the beginning of the sample were replaced with the averages of the single series as to not add unnecessary variability.

4 The Model

This Section will present a simpler version of the model utilized to produce the stochastic simulations of both area–wide shocks and single Country shocks, in order to provide the reader with a cleaner and more intuitive framework for the interpretation of the results. The utilized model is the one described in Erceg and Lindé (2013), and the reader is strongly encouraged to refer to the original work for a more detailed tractation.

As previously mentioned in Section 2, the employed framework for the analysis is that of a two–country open economy New Keynesian DSGE model that incorporates both nominal price and wage rigidities. The model also displays a number of features – such as variable capital utilization, non–Ricardian households and financial frictions – from which this Section will abstract, for simplicity[18]. The model describes a Currency Union (CU) formed by two country blocks, Core and Periphery, that are identical in most aspects, except for size (as percentage of the whole CU), trade shares and fiscal policy conduction. Section 4.1 will describe the maximization problems faced by the agents, whereas Section 4.2 will provide the log–linearized form of the equations that characterize the model.

Please note that the variables marked by * in the following refer to the foreign economy's variables, which, in our case, is assumed to be the Core block.

4.1 Economic Agents

4.1.1 Firms

In our simplified framework we observe two types of firms: *final good firms* that produce a single domestic output good and *intermediate firms* that produce the intermediate goods that are used as inputs for the final good's production.

- **Final good firms**

A single final domestic output good, Y_{Dt}, is produced by combining a continuum of

[18]Please note that these features help in generating more economically reasonable results. Refer to the original work for further tractation.

differentiated intermediate goods $Y_{Dt}(f)$ via the following Dixit–Stiglitz technology:

$$Y_{Dt} = \left[\int_0^1 Y_{Dt}(f)^{1/1+\theta_p} \, df \right]^{1+\theta_p}$$

where $\theta_p > 0$ describes the price markup. Final good firms are assumed to be perfectly competitive in both product and factor markets, hence they minimize the cost of producing a given amount of Y_{Dt} subject to the price $P_{Dt}(f)$ of each intermediate good. The final output good is sold at price P_{Dt}, which is interpreted as the aggregate domestic price index :

$$P_{Dt} = \left[\int_0^1 P_{Dt}(f)^{\frac{-1}{\theta_p}} \, df \right]^{-\theta_p}$$

The foreign economy is assumed to be isomorphic to the home one, so the price index and production technology look identical. Namely,

$$Y^*_{Dt} = \left[\int_0^1 Y^*_{Dt}(f)^{1/1+\theta_p} \, df \right]^{1+\theta_p}$$

and

$$P^*_{Dt} = \left[\int_0^1 P^*_{Dt}(f)^{-1/\theta_p} \, df \right]^{-\theta_p}$$

Let us define the notation for the price of imported goods M_t and M^*_t : they are sold at prices P^*_{Mt} and P_{Mt}, respectively, in the home and foreign economies. We assume that the price of the final good is the same regardless of where it is sold; in other words the law of one price holds. Namely, we have $P^*_{Mt} = P_{Dt}$ and $P_{Mt} = P^*_{Dt}$.

- **Intermediate Good Firms**

We assume that intermediate goods are produced by a continuum of monopolistically competitive firms, that transform capital and labour into intermediate goods via a Cobb–Douglass production function:

$$Y_{Dt}(i) = K(i)^{\alpha}(Z_t L_t(i))^{1-\alpha}$$

Where Z_t is a stationary, country–specific technology shock. The firm chooses $K(i)$ and $L_t(i)$ taking their respective prices, R_{Kt} and W_t as given and, since both inputs are assumed to be perfectly mobile within a country, all firms face the same marginal costs:

$$MC_t = \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_{kt}}{\alpha}\right)^{\alpha} Z_t^{\alpha-1}$$

Intermediate firms face the following demand at home, $Y_{Dt}(i)$, and in the foreign country[19], $X_{Dt}(i)$:

$$Y_{Dt}(i) = \left[\frac{P_{Dt}(i)}{P_{Dt}}\right]^{\frac{-(1+\theta_p)}{\theta_p}} Y_{Dt}$$

$$X_{Dt}(i) = \left[\frac{P^*_{Mt}(i)}{P^*_{Mt}}\right]^{\frac{-(1+\theta_p)}{\theta_p}} M^*_t$$

Where P^*_{Mt} is the foreign import price index. Intermediate goods firms set prices according to Calvo–style staggered contracts: namely, each firm i has a positive probability $1-\xi_p$ of being able to reoptimize its price ($P_{Dt}(i)$) each period[20].

Firms that are not able to reoptimize update their prices by the steady–state inflation rate according to the following:

$$\tilde{P}_{Dt}(i) = (1+\pi_D)P_{Dt-1}(i)$$

where $\tilde{P}_{Dt}$ denotes the price set by non–reoptimizing firms. Given the nominal frictions described above, reoptimizing firms solve the following problem:

$$max_{P^{opt}_{Dt}(i)}\ E_t\sum_{j=0}^{\infty}\xi_p^j\psi_{t,t+j}\Big[(1+\pi_D)^j P^{opt}_{Dt}(i) - MC_{t+j}\Big]Y_{Dt+j}(i)$$

where E_t represents conditional expectatons based on the available information set at time t, $P^{opt}_{Dt}(i)$ is the optimal price and $\psi_{t,t+j}$ the stochastic discount factor, that represents the conditional value of future profits in utility units. Keeping in mind that all firms face the same costs for inputs (which implies that all reoptimizing firms will choose the same price) and that final goods firms are perfectly competitive price–takers,

[19]Note: for expositional simplicity, the rest of the description will abstract from the foreign demand.

[20]Please note that the probability $1-\xi_p$ is independent of its previous realizations, i.e. a firm that has reoptimized its price in period $t-1$ is not less likely to be able to reoptimize in period t compared to a firm that has not.

we can describe the evolution of the aggregate final good price in the following manner:

$$P_{Dt} = \left[(1-\xi_p)(P_{Dt}^{opt})^{\frac{-1}{\theta_p}} + \xi_p((1+\pi)P_{Dt-1})^{\frac{-1}{\theta_p}} \right]^{-\theta_p}$$

4.1.2 Households

In this simplified framework, we assume a continuum of utility–maximizing households[21] that are subject to a budget constraint. Households are also monopolistically competititive suppliers of labour services to the intermediate good firms: wage setting is modelled in a Calvo–style framework, similarly to price setting for intermediate good firms.

Each household h's preferences are described by the following utility function:

$$E_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1}{1-\sigma}(C_{t+j}(h) - \varkappa C_{t+j-1} - \nu_{Ct})^{1-\sigma} + \frac{\chi_0}{1-\chi}(1-N_{t+j}(h))^{1-\chi} + \mu_0 F\left(\frac{MB_{t+j+1}(h)}{P_{Ct+j}}\right)\right\}$$

Households derive positive utility from consumption ($C_{t+j}(h)$), leisure $(1 - N_{t+j}(h))$ and holdings of real money balances[22] ($F\left(\frac{MB_{t+j+1}(h)}{P_{Ct+j}}\right)$); deviations from habitual consumption (C_{t+j-1}, aggregate past consumption is used as a reference by households) and taste shocks (ν_{Ct}) instead generate negative utility.

The parameter $\varkappa$ describes the degree of habit formation in consumption, β is the discount rate, and χ_0 describes the disutility of working perceived by the household. Furthermore, we assume that $\beta \in (0,1)$, $\chi > 0$, $\chi_0 > 0$ and $\mu_0 > 0$ but arbitrarily small.

Households derive utility from the consumption of both domestically produced (C_{Dt}) and imported (M_{Ct}) consumption goods, that constitute the following consumption bundle:

$$C_t = \left((1-\omega_C)^{\frac{\rho_C}{1+\rho_C}} C_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C^{\frac{\rho_C}{1+\rho_C}} M_{Ct}^{\frac{1}{1+\rho_C}} \right)^{1+\rho_C}$$

The parameter ω_C describes the preference of households for domestic goods relative to imported goods. This degree of home bias plays an important role in determining

[21] Please note that in this simplified exposition we abstract from the presence of non–Ricardian, or hand–to–mouth, households.

[22] The parameter μ_0 is assumed to be arbitrarily small, for simplicity, so that real money balances can be ignored.

the openness to trade of each block: in fact, the higher ω_C, the more preferences are tilted towards foreign–produced consumption goods. The demand for each kind of consumption good is determined by their price relative to the whole bundle's, namely

$$M_{Ct} = \omega_C \left(\frac{P_{Mt}}{P_{Ct}} \right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t$$

and

$$C_{Dt} = (1 - \omega_C) \left(\frac{P_{Dt}}{P_{Ct}} \right)^{\frac{-(1+\rho_C)}{\rho_C}} C_t$$

and the bundle's price is given by:

$$P_{Ct} = \left((1 - \omega_C) P_{Dt}^{\frac{1}{1+\rho_C}} + \omega_C P_{Mt}^{\frac{1}{1+\rho_C}} \right)^{1+\rho_C}$$

Please note that the CB targets HICP inflation, i.e. the change in the price of consumption described by the above formula.

As previously mentioned, households are monopolistilcally competitive suppliers of labour: we assume that there is a continuum of households (h), whose services are aggregated by an "employment agency" to build the following aggregate labour index:

$$L_t = \left[\int_0^1 (\zeta N_t(h))^{\frac{1}{1+\theta_w}} dh \right]^{1+\theta_w}$$

where ζ describes the size of the household (and, effectively, the population size of each country block), θ_w is the elasticity of demand for each labour type and $N_t(h)$ are each household's hours worked. The employment agency is a price–taker that "sells" units of labour to the intermediate firms at cost. Namely, it minimizes the cost of "aggregating" a given amount of labour index taking its price (each household's nominal wage $W_t(h)$) as fixed. This implies that the demand for labour services faced by each household is the following:

$$N_t(h) = \left[\frac{W_t(h)}{W_t} \right]^{-\frac{1+\theta_w}{\theta_w}} \frac{L_t}{\zeta}$$

where the aggregate wage index is given by:

$$W_t = \left[\int_0^1 W_t(h)^{-\frac{1}{\theta_w}} dh \right]^{-\theta_w}$$

Note that the relationship between households and the employment agency is remarkably similar to the previously described one between final and intermediate good firms. In fact the same staggered, Calvo–style contract is assumed to generate nominal rigidities in the wage setting process. Namely, each household has a positive probability $(1-\xi_w)$ of being able to renegotiate its wage each period; the share of households that isn't able to reoptimize their wage updates it according to the following :

$$W_t(h) = (1+\pi_w)W_{t-1}(h)$$

where π_w is the steady–state net wage inflation, $\frac{W_t}{W_{t-1}} - 1$.

Households, taking into account the presence of nominal rigidities, maximize their utility subject to the constraint implied by the formers and to the following budget constraint:

$$P_{Ct}(1+\tau_{Ct})C_t(h) + \int_s \xi_{t,t+1}B_{t+1}(h) - B_t(h) + B_{Gt}(h) = (1-\tau_{Nt})W_t(h)N_t(h) + \\ + R_{Kt}K + (1+i_{t-1})B_{Gt-1}(h) + \Gamma_t(h) + TR_t(h)$$

We assume that the household is able to trade in internationally complete financial markets, where it can purchase contingent claims $(B_{t+1}(h))$ that will pay one unit of currency in a particular state at time $t+1$ at price $\int_s \xi_{t,t+1}$. The above states that the expenditure on consumption $(P_{Ct}(1+\tau_{Ct})C_t(h))$, on contingent claims and on government bonds (B_{Gt}) must equal after tax labour income $((1-\tau_{Nt})W_t(h)N_t(h))$, plus the income derived from renting the fixed stock of capital each household is endowed with to firms $(R_{Kt}K)$, the income derived from holding government bonds $((1+i_{t-1})B_{Gt-1}(h))$, the dividends from firms' profits, $\Gamma_t(h)$, and lump–sum taxes and transfers from the government $(TR_t(h))$.

4.1.3 Government, aggregate variables and monetary policy

The central government does not balance its budget every period, it simply issues new debt in order to finance its deficits according to the following:

$$B_{Gt} = (1+i_{t-1})B_{Gt-1} + P_{Gt}G_t - \tau_{Ct}P_{Ct}C_T - \tau_{Nt}W_tN_t - TR_t$$

The governmentt issues new debt (B_{Gt}) to finance its payments on outstanding debt ($(1+i_{t-1})B_{Gt-1}$) and its consumption ($P_{Gt}G_t$), while it receives tax income from private consumption ($\tau_{Ct}P_{Ct}C_t$), labour income ($\tau_{Nt}W_tN_t$) and lump–sum taxes minus transfers (TR_t). Scaling the above with $1/P_{Dt}Y$ (nominal trend GDP), we obtain

$$b_{Gt} = \frac{(1+i_{t-1})}{(1+\pi_{Dt})} b_{Gt-1} + \frac{P_{Gt}}{P_{Dt}}\frac{G_t}{Y} - \tau_{Ct}\frac{P_{Ct}}{P_{Dt}}\frac{N_t}{Y} - \frac{TR_t}{P_{Dt}Y}$$

where b_{Gt} represents government debt as a share of (nominal trend) GDP.

Government consumption, G_t, is modelled exactly like private consumption. The government consumes a bundle of domestic and imported goods at price P_{Gt} that are described by the following two equations:

$$G_t = \left((1-\omega_G)^{\frac{\rho_G}{1+\rho_G}} G_{Dt}^{\frac{1}{1+\rho_G}} + \omega_G^{\frac{\rho_G}{1+\rho_G}} M_{Gt}^{\frac{1}{1+\rho_G}} \right)^{1+\rho_G}$$

and

$$P_{Gt} = \left((1-\omega_G) P_{Dt}^{\frac{1}{1+\rho_G}} + \omega_G P_{Mt}^{\frac{1}{1+\rho_G}} \right)^{1+\rho_G}$$

As in the consumption good case, ρ_G describes the willingness of the government to switch between domestic and imported goods and ω_G measures the government's import share of consumption.

Both governments (i.e. Core and Periphery governments) are assumed to conduct fiscal policy according to the following equation[23] :

$$\tau_{Nt} = \nu_0 \ \tau_{Nt-1} \ + \ (1-\nu_0)[\nu_1 \ (b_{Gt} - \bar{b}) + \ \nu_2 \ \Delta b_{Gt}] + \epsilon_{\tau t}$$

The fiscal instrument (the labour income tax τ_{Nt}) is adjusted as a response to the deviation of the debt to GDP ratio (b_{Gt}) from its desired level ($\bar{b}$) and the increases or decreases of the ratio. The parameters ν_1 and ν_2 capture the response to movements in the debt to GDP ratio, whereas the parameter ν_0 describes the dependence of the current tax rate on its past values. The latter can be interpreted as describing the aggressiveness of the government's fiscal policy: the greater ν_0, the less the tax rate will deviate from its previous values to accomodate changes in the debt to gdp ratio. In this analysis, the fiscal policy is modelled differently for the two country blocks, contrarily

[23] Note that the equation is expressed in its log–linearized form.

to the majority of the other parameters. Namely, the Periphery is assumed to follow an aggressive fiscal policy ($\nu_0 = 0.5$, $\nu_1 = 0.5$, $\nu_2 = 0.25$) whereas the Core is assumed to follow a non–aggressive policy ($\nu_0 = 0.985$,$\nu_1 = 0.1$,$\nu_2 = 0.1$) as in the original work. We also allow for the presence of an exogenous shock, $\epsilon_{\tau t}$ which we assume follows an AR(1) process, i.e. $\epsilon_{\tau t} = \rho_{\tau_N}\epsilon_{\tau t-1} + \varepsilon_t$, where $\rho_{\tau_N} < 1$.

Monetary policy is described by the Taylor rule presented in Section 3. Please note that the CB reacts to movements in *union–wide variables* that are defined as follows:

$$\pi_t^{CU} = \varphi^C \pi_{Ct}^* + \varphi^P \pi_{Ct}$$

where φ^C is the weight *assigned by the CB* to Core HICP inflation and φ^P is the weight *assigned by the CB* to periphery HICP inflation[24].

It is important to note that the weights of each block, *relative to the variables that enter the Taylor rule*, are assigned by the CB rather than being the relative population shares as in the original work: this departure from Erceg and Lindé (2013) is necessary to analyze the sensitivity of monetary and fiscal policies to different weights (i.e. importance) assigned by the CB to each country block. Please note that the only change is made on the weights that enter the Taylor rule: the actual economic weights (and their effects on e.g. trade dynamics) are left untouched.

Currency union output gap, similarly, is defined as

$$x_t^{CU} = \varphi^C x_t^* + \varphi^P x_t$$

where each block's (log–linearized) output gap is defined as follows:

$$x_t = y_t - y_t^{pot}$$

where y_t is log–linearized GDP and y_t^{pot} is its potential counterpart, i.e. the level of GDP that would prevail in a flex–price economy.

Lastly, the aggregate resource constraint for the home economy is given by

$$Y_{Dt} = C_{Dt} + G_{Dt} + \frac{\zeta^*}{\zeta}[M_{Ct}^* + M_{Gt}^*]$$

[24]The reader should recall that variables indexed by * refer to the foreign economy. In this case, we are treating the Core block as the foreign economy.

where exports are weighted by the relative population size of foreign to home country, as the two variables are expressed in per capita terms. The corresponding foreign economy aggregate constraint is given by:

$$Y^*_{Dt} = C^*_{Dt} + G^*_{Dt} + \frac{\zeta}{\zeta^*}[M_{Ct} + M_{Gt}]$$

To conclude, we assume that trade is balanced on a good–by–good basis, which implies that

$$\zeta\omega_C = \zeta^*\omega^*_C$$

and

$$\zeta\omega_G = \zeta^*\omega^*_G$$

hence, we normalize

$$\zeta + \zeta^* = 1$$

4.2 Model log–linearized characterization

Having described the problems faced by the agents, we now provide a full characterization of the log–linearized version of the model. Please remember that the following is a simplified model that aims at providing the reader with a more compact and intuitive framework; the original model also includes non–Ricardian households, variable capital utilization and a financial accelerator block that we abstract from. Note that lower–case variables are expressed in percentage deviation from their steady–state value (i.e. they are log–linearized); taxes, inflation and interest rate were not log–linearized as they are already expressed in percentage terms. Please also note that, for the sake of expositional simplicity, the following equations abstract from habit persistence in consumption ($\varkappa C_{t-1}$) and from exogenous taste shocks (ν_{Ct}).

Price setting is described by the standard New Keynesian Phillips Curve (NKPC), which is derived from firms' first order conditions and the aggreate price index evolution, for both single country blocks and the whole CU:

$$\pi^{CU}_t = \beta E_t \pi^{CU}_{t+1} + \kappa_{mc}[\phi_x x^{CU}_t] \qquad (M.1)$$

$$\pi_{Dt} = \beta E_t \pi_{Dt+1} + \kappa_{mc} mc_t \qquad (M.2)$$

$$\pi^*_{Dt} = \beta E_t \pi^*_{Dt+1} + \kappa_{mc} mc^*_t \qquad (M.3)$$

Wage setting incorporates the same frictions as price setting does, hence it is described by a similar equation, the so–called wage NKPC:

$$\pi_{wt} = \beta E_t \pi_{wt} + \kappa_w \mu^w_t \qquad (M.4)$$

and its foreign counterpart

$$\pi^*_{wt} = \beta E_t \pi^*_{wt} + \kappa_w \mu^{w*}_t \qquad (M.5)$$

where π_{wt} represents log–linearized wage inflation, i.e. $w_t - w_{t-1}$ and μ^w_t represents the wage markup, which can be thought of (in log–linearized terms) as the difference between real wage and the marginal rate of substitution between consumption and leisure[25]. A more intuitive explaination for the wage markup term could be real wage's deviation from its potential value.

Marginal costs evolve according to the following (since the two economies are mostly isomorphic, we will only present the expression for domestic marginal costs):

$$mc_{Dt} = \bar{w}_{Ct} - \bar{w}^{pot}_{Ct} + \omega_C(\gamma_{MDt} - \gamma^{pot}_{MDt}) + \frac{\alpha}{1-\alpha}(y_{Dt} - y^{pot}_{Dt}) \qquad (M.6, M.7)$$

where $\bar{w}_{Ct}$ and $\bar{w}^{pot}_{Ct}$ are respectively real wage and potential real wage (measured in consumption units), γ_{MDt} are the foreign terms of trade (i.e the relative price of imports to domestic goods), γ^{pot}_{MDt} their potential counterpart, and y_{Dt} and y^{pot}_{Dt} are actual and potential domestic GDP.

An alternative representation for marginal costs (both domestic and foreign) is the following :

$$mc_{Dt} = \frac{1}{\sigma}c_t + \frac{\tau_{Nt}}{1-\tau_N} + \frac{\tau_{Ct}}{1-\tau_C} + \omega_C \gamma_{MDt} - (1+\chi)z_t + \frac{\chi+\alpha}{1-\alpha}y_{Dt}$$

[25]See also Galì (2010) for a deeper tractation of the wage NKPC. We refer to this work as it presents an intuitive explaination of the wage NKPC.

As is clear from (M.6,M.7), marginal costs in both countries depend on the cost of labour (in the alternative representation, real wage has been substituted with its equivalent consumption choice made by the household, which derives from the marginal rate of substitution between consumption and labour), trade openness and the terms of trade and from the quantity of output produced.

Terms of trade are described by the following:

$$\gamma_{MDt} = \pi_{Mt} - \pi_{Dt} + \gamma_{MDt-1} \qquad (M.8)$$

where π_{Mt} is exports' price inflation and π_{Dt} is domestic good's price inflation. Please note that, as the law of one price holds, we have:

$$\pi_{Mt} = \pi^*_{Dt} \qquad (M.9)$$

Please note that HICP inflation (the relevant one for monetary policy) is defined as follows, in both country blocks:

$$\pi_{Ct} = (1 - \omega_C)\pi_{Dt} + \omega_C \pi_{Mt} \qquad (M.10, M.11)$$

Consumption, in both blocks, is described by the familiar consumption Euler equation, derived from the households' first order conditions:

$$c_t = E_t c_{t+1} - \sigma(i_t - E_t \pi_{Ct+1}) + \frac{\sigma}{1 + \tau_C} \Delta E_t \tau_{Ct+1} \qquad (M.12, M.13)$$

Aggregate resource constraints are described by

$$y_{Dt} = \left[\omega_C \frac{(1+\rho_C)}{\rho_C} s_{cy}(2 - \omega^*_C - \omega_C) + \omega_G \frac{(1+\rho_G)}{\rho_G} s_{gy}(2 - \omega^*_G - \omega_G)\right]\gamma_{MDt} +$$
$$+ s_{cy}c_t + s_{gy}g_t - \omega_C s_{cy}(c_t - c^*_t) - \omega_G s_{gy}(g_t - g^*_t) \qquad (M.14, M.15)$$

where s_{cy} is the private consumption's share of output and s_{gy} is the public consumption's share of output, i.e. $s_{xy} = X/Y_D$ for $X = \{C, G\}$.

Each country's fiscal policy is described by the equation presented in 4.1:

$$\tau_{Nt} = \nu_0\ \tau_{Nt-1}\ +\ (1 - \nu_0)[\nu_1\ (b_{Gt} - \bar{b}) +\ \nu_2\ \Delta b_{Gt}] + \epsilon_{\tau t} \qquad (M.16)$$

Lastly, together with (M.1), the following equations describe the aggregate economy: note that the model resembles a closed economy DSGE model if only the CU is described.

Monetary policy is described by the Taylor rule presented in Section 3,

$$i_t = (1-\rho)[R + \gamma_\pi(E_t[\pi^{CU}_{t+12}|\Omega_t] - \pi^*) + \gamma_x E_t[x^{CU}_{t+3}|\Omega_t]] + \rho i_{t-1} + \epsilon_t \qquad (M.17)$$

whereas aggregate output gap is defined by:

$$x^{CU}_t = \varphi^C x^*_t + \varphi^P x_t \qquad (M.18)$$

or, alternatively, by:

$$x^{CU}_t = E_t x_{t+1} - c_y \sigma (i_t - E_t \pi^{CU}_{t+1} - r^{CU,pot}_t)$$

where c_y is the aggregate consumption's share of aggregate GDP and $r^{CU,pot}_t$ is the aggregate potential real rate.

An alternative representation of (M.1), as for x^{CU}_t, is given by

$$\pi^{CU}_t = \varphi^C \pi^*_{Ct} + \varphi^P \pi_{Ct}$$

5 Methodology and weighting schemes

In order to answer the research question described in Section 1 the following procedure was enacted: firstly, an empirical reaction function was estimated from the data as to describe the behaviour of the ECB during the analyzed time frame (1999:01–2007:12). Secondly, the rule was embedded in the New Keynesian DSGE model developed in Erceg and Lindé (2013), which was slightly altered to allow for different fiscal policy conduction in the two country blocks. Lastly, two exogenous shocks to the system were analyzed through the simulated impulse response functions (henceforth IRFs) generated by the model.

The exogenous shocks were chosen to analyze the response to two different kinds of stimuli: a systemic one, meaning a shock that affects a variable common to the whole

CU, and an idiosyncratic one, meaning a shock that originates from a single member of the CU. Namely, the former (systemic stimulus) was simulated as a one percent increase in the common interest rate set by the CB (i_t), whereas the latter (idiosyncratic stimulus) was simulated as a one percent increase in the fiscal instrument (i.e. the labour income tax rate τ_{Nt}) of the Periphery block[26]. The simulation was conducted in five different scenarios, each of which assumes a different weighting assigned by the CB to each Country block. The reader should keep in mind that only the weights relative to the conduction of monetary policy (i.e. φ^C and φ^P, that appear only in the Taylor rule through π_t^{CU} and x_t^{CU}) were changed in this scenario analysis, whereas the actual economic size of the blocks (that has an important role in determining trade related parameters) was left untouched.

As mentioned above, fiscal policy was modelled differently in the two blocks: the Periphery is assumed to respond aggressively to movements in the debt to GDP ratio, whereas the Core is assumed to respond more gradually, adjusting its tax rate slowly. In practice, the parameters in Equation (M.16) were set[27] according to the following table:

Parameter	Core	Periphery
ν_0	0.985	0.5
ν_1	0.1	0.5
ν_2	0.1	0.25

Table 4: Fiscal Policy Parameters

5.1 The simulations: different weights scenarios

Four scenarios were simulated, along with the baseline calibration, that differ in the weight assigned to each country block by the CB in the monetary policy conduct. The two country blocks are composed of Greece, Italy, Portugal and Spain for the Periphery and Austria, Belgium, Germany, Finland, France, Ireland, Luxembourg and

[26] Appendix C plots the IRFs to a fiscal shock in the Core. The reader is invited to refer to it for comparison, although their interpretation does not lead to different conclusions. Please note that the Periphery was chosen to be subject to the shock as to be coherent with the original work.

[27] All the other parameters (except for the Taylor rule's coefficients presented in Section 3) are left as calibrated by Erceg and Lindé (2013).

the Netherlands for the Core. Note that the five biggest economies of the Euro Area (Germany, France, Italy, Spain and the Netherlands) represent 85% of the total economic weight of the modelled currency union. The following table presents the five scenarios and the weights, in percentage, that each block is assigned. Please note that the weights in the "Importance to Core" and "Importance to Periphery" scenarios are assigned arbitrarily, so to have a representation of the implications of the CB mostly focusing on one country block.

Scenario	φ^C	φ^P
Baseline	64%	36%
Equality	50%	50%
Importance to Core	90%	10%
Importance to Periphery	10%	90%
Germany as Core	29%	71%

Table 5: Policy rule weight parameters

6 Results

6.1 The Results: simulated IRFs

For the systemic shock described above, the following graphs plot the response of each block's GDP (y_t and y_t^*), HICP inflation (π_{Ct} and π_{Ct}^*), debt to GDP ratio (b_{Gt} and b_{Gt}^*) and labour tax rate (τ_{Nt} and τ_{Nt}^*). Please recall that variables marked by * refer to Core variables. Instead, for the idiosyncratic shock, the responses of real GDP, output gap (x_t and x_t^*), the policy rate (i_t) and HICP inflation are plotted. In the former case, the interest is focused on the reaction of the single blocks to the shock, as described by their independent fiscal policy and by the conventional measures of economic activity (real GDP, inflation). In the latter case, the response of the single fiscal policies and debts are substituted with the output gap's and interest rate's ones, as the focus is on the behaviour of monetary policy and its repercussions on the two blocks.

6.1.1 Responses of Periphery variables to a systemic shock

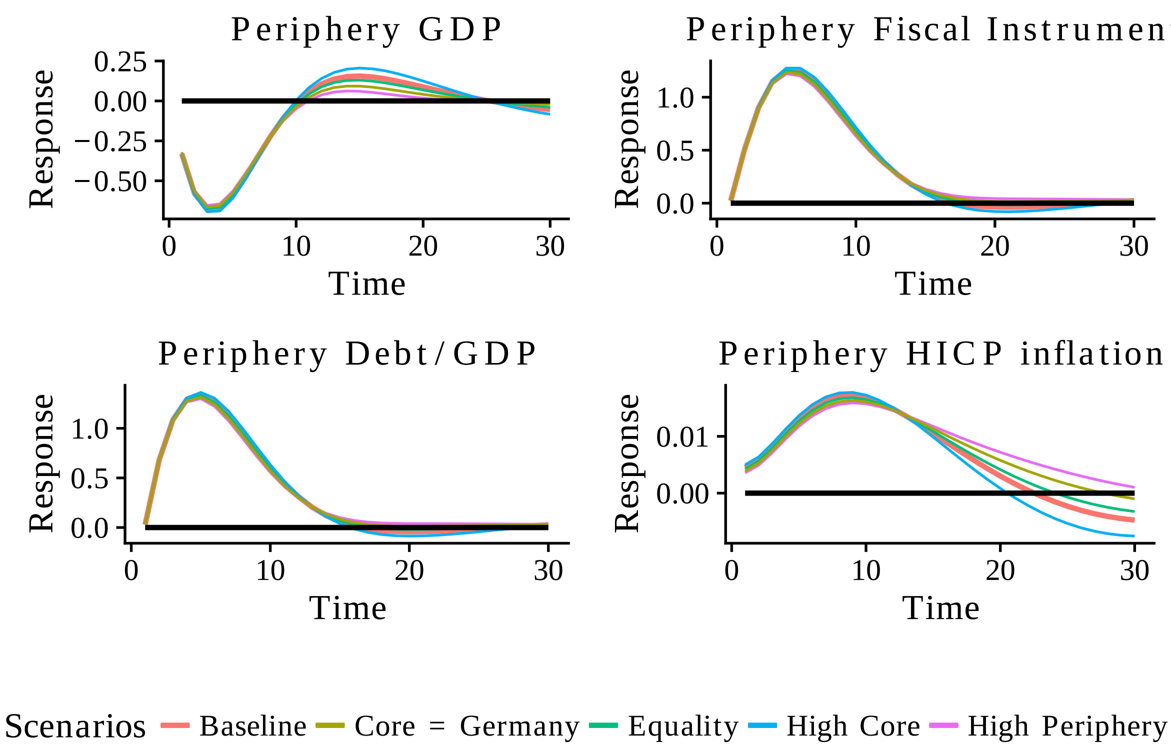

Figure 4: Periphery responses to a policy shock

The IRFs presented above suggest that no matter how much importance the CB gives to the peripheral block, the responses to a systemic shock do not sensibly change. In other words, the economy's reaction does not seem to be sensitive to the weight it is given by policymakers when they conduct monetary policy.

Focusing the attention on each single graph, we can see that GDP shows a sharp decline around period 5 and then returns to pre–shock levels after roughly ten periods. There appears to be some slight difference in the readjustment process: in fact the IRFs seem to separate slightly around period ten, to then converge back to pre–shock levels. It appears that the more weight the Periphery block has, the faster the stabilization around the equilibrium will be, but on the other hand, a higher weight to the Core seems to produce greater growth after the recovery. Please note, though, that the magnitude of the differences is rather small (0.25%).

The response of b_{Gt} is in line with expectations: the ratio increases as a higher interest rate implies more interest payments to be made, and hence more debt needs to be issued. Coherently, fiscal policy responds by raising the labour income tax as a reaction to the increase in debt, as described by (M.16). In this case, regardless of the importance that the peripheral economies are given by the CB, their adjustment path to a policy shock does not change. Lastly, inflation displays an unusually large "price puzzle". Please note that "price puzzle" refers to the widely documented[28] positive, hump–shaped response of inflation to a contractionary monetary policy shock.

This observed behaviour is due to the large degree of rigidities present in the model; apart from price (ξ_p) and wage rigidities (ξ_w), there are also investment adjustment costs, variable capital costs and consumption adjustment costs which Section 4 abstracted from, for simplicity. The price puzzle is less persistent the more weight the CB gives to the Core in the conduction of monetary policy.

[28]See, for example, CEE(2005).

6.1.2 Responses of Core variables to a systemic shock

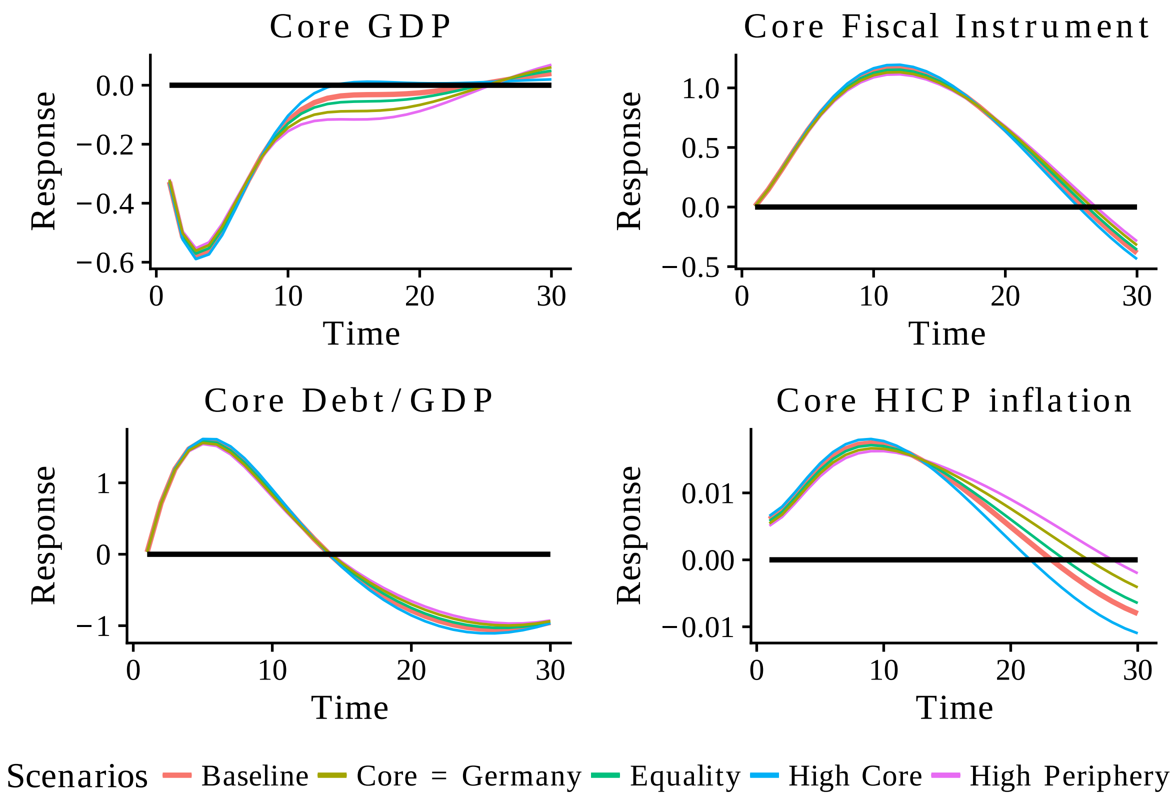

Figure 5: Core responses to a policy shock

The same consierations outlined for the previously presented IRFs can be seen to hold for the Core as well. GDP responds to a one percent increase in the policy rate according to expectations, together with the fiscal instrument and the debt to GDP ratio. Note that the latter two exhibit a more sluggish response compared to their Periphery counterparts: this is in line with the less aggressive fiscal policy in the Core. In fact, we observe that the response of the fiscal instrument peaks well after the debt to GDP ratio has started converging back to its steady–state level. As a consequence, b^*_{Gt} does not stabilize back around its steady state, but rather continues decreasing as the government is still receiving "extra" labour tax revenue. GDP behaves accordingly to expectations: the more weight the core has, the faster its stabilization around pre–shock levels. Lastly, HICP inflation behaves similarly to the Periphery's: the higher the weight on core economies, the less persistent the price puzzle.

6.1.3 Responses of Periphery variables to an idiosyncratic shock

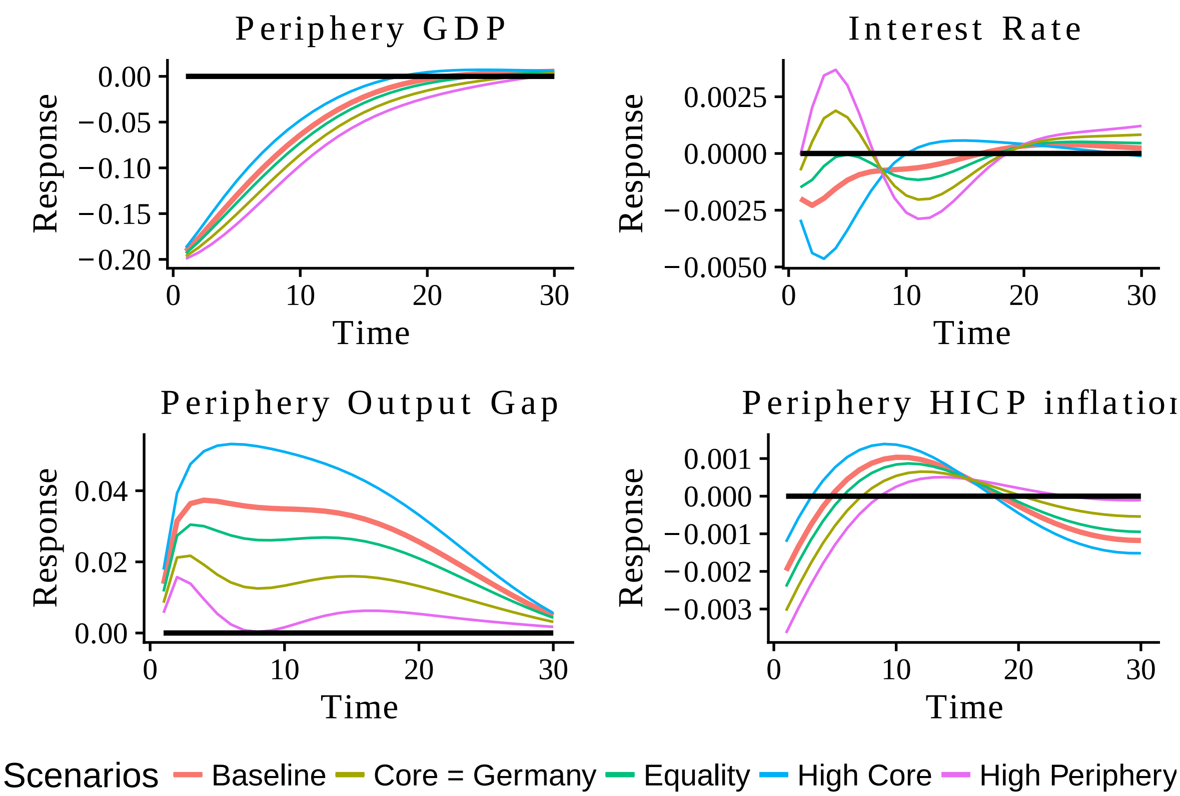

Figure 6: Periphery responses to a peripheral fiscal shock

From the above graphs, it appears that a greater weight to core economies is associated with faster convergence to pre–shock levels. GDP shows the same initial negative response (-0.2%) in all cases but, as stated above, the higher the importance of core economies in the conduction of monetary policy, the faster it converges back to equilibrium. Potential GDP, instead, is not sensitive to the different weights assigned by the policymaker. Please recall that potential GDP is defined as the level of output that would prevail in a frictionless economy: clearly, monetary policy does not have an effect on real variables in such a setting. This explains the observed reaction of output gap: real GDP always displays a less negative response, hence, in all scenarios, output gap deviates positively from equilibrium levels. This is reflected in the reaction of monetary policy: as HICP inflation barely moves, when compared to the output gap, the reaction to the latter will be determining the appropriate response of the interest rate (also given the high value of γ_x – the output gap coefficient – in the estimated

Taylor rule). The importance of the weights attributed to each block is clearly pivotal in determining the reaction of monetary policy: it will be further discussed shortly.

6.1.4 Responses of Core variables to an idiosyncratic shock

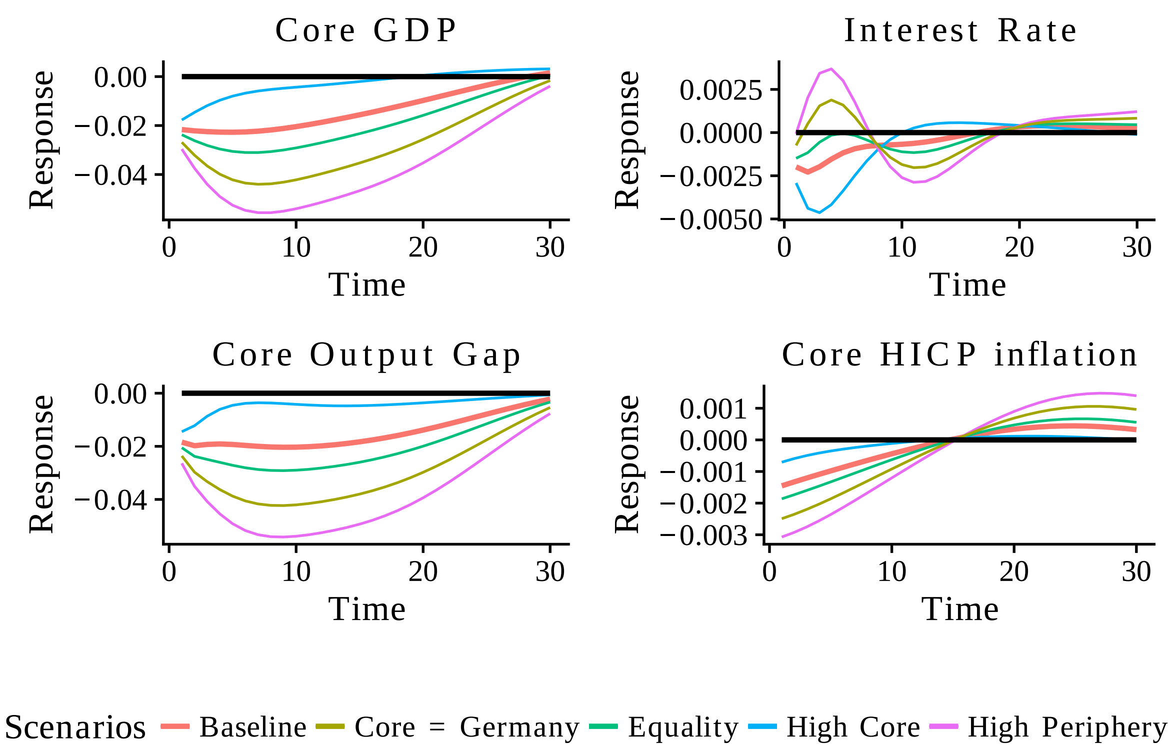

Figure 7: Core responses to a peripheral fiscal shock

As was the case for the Periphery, potential output does not react differently to a tax hike in the Periphery across scenarios, but there is a major difference when comparing its reaction to its peripheral counterpart: the magnitude of the former's response is rather small, almost negligible. In fact, the responses of real GDP and output gap are almost identical and hence, contrarily to what was observed for the Periphery, output gap in the Core drops following a fiscal shock in the periphery. HICP inflation behaves similarly to its counterpart in the Periphery: the response is negative, but small in magnitude due to the aforementioned rigidities.

6.1.5 Response of monetary policy to an idiosyncratic shock

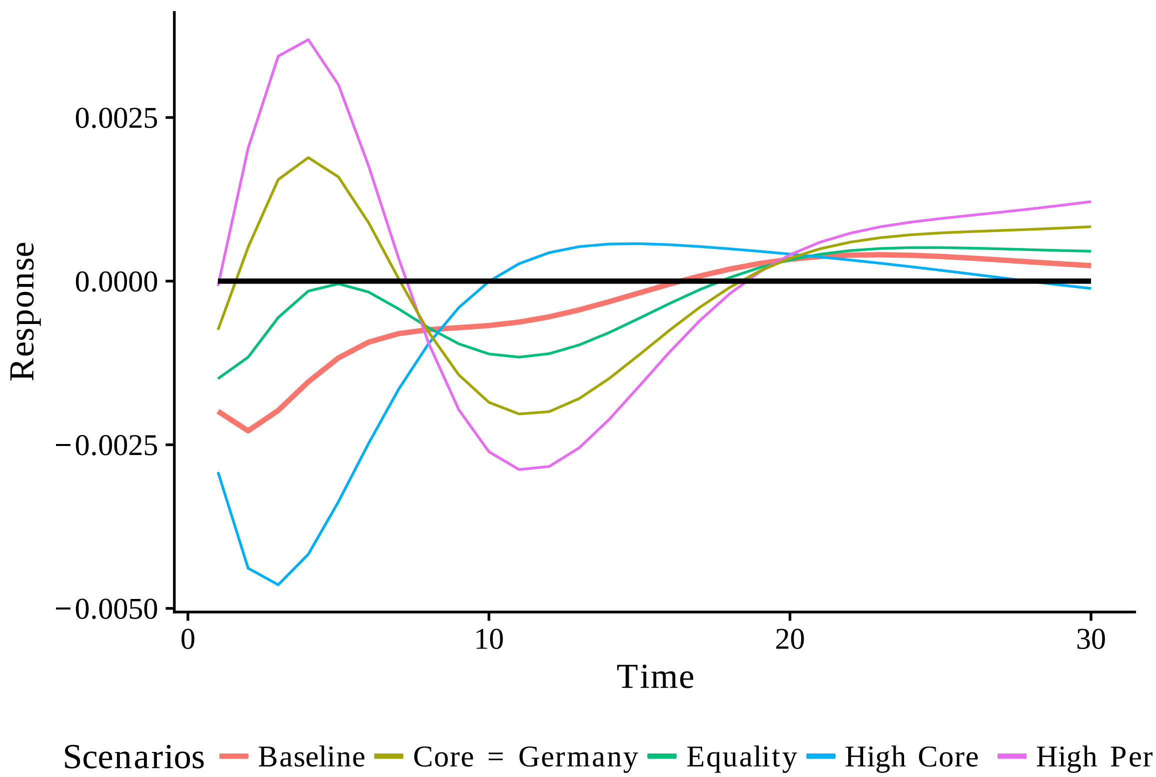

Figure 8: CB's response to a peripheral fiscal shock

As was briefly mentioned above, the response of monetary policy to a fiscal shock in the Periphery is greatly dependent on the movement of output gap, for two main reasons: firstly, the coefficient determining the response was estimated to be rather high and secondly, HICP inflation displays a minimal response (in terms of magnitude) to a sudden increase in the labour income tax rate in the Periphery. Given that the main responsible for movements in the policy rate is output gap, it is clear that the role of the parameters φ^P and φ^C is of extreme importance. In fact, a great weight of peripheral economies ("High Periphery Weight" and "Core=Germany" scenarios) produces a contractionary reaction, as the CB attempts to close the output gap, which has positively deviated from equilibrium. This, in turn, causes the slower adjustment process of HICP inflation and real GDP in both blocks. Conversely, a higher weight on Core economies (whose output gap displays a negative response) causes a drop in the policy rate, which, being an expansionary measure, helps the recovery in both blocks.

Lastly, Appendix C displays the IRFs of the above variables to a fiscal shock in the Core: whereas the results are qualitatively similar, it is possible to observe that the reaction of monetary policy is always expansionary. The greatest difference between the responses to the idiosyncratic shocks is that, when the CB gives the most importance to the Core – where the shock originates – the Core's output gap does not react as much as the Periphery's does when the shock originates from the Periphery. As per the mechanics explained above, monetary policy reacts accordingly, cutting the policy rate to help the recovery in the whole Union.

7 Discussion

This section will discuss the results presented in Section 6, aiming at providing the reader with an interpretation of the latters as well with the insights that can be extracted from the differences in the analyzed scenarios. The reader should keep in mind that the IRFs, and hence the conclusions derived from their observation, are clearly dependent on the model employed for the analysis. Recalling Section 2, the chosen framework was deemed the most appropriate due to the following reasons: firstly, the DSGE framework, on top of being a standard instrument in the literature, is also chosen as the basis for more complicated models by CBs[29]. Secondly, the model was specifically developed to analyze a currency union (even though for a different purpose from the one of this thesis) and hence embeds the appropriate features to conduct this analysis, namely a common monetary policy conduction and independent fiscal policies for each member of the CU, together with an open economy dimension, as is the peculiar case of the Euro Area. Lastly, the model embeds realistic features that make it a suitable choice when giving importance to both plausibility of results and tractability of both the framework and the results it generates.

7.1 Reactions to a systemic shock

Sections 6.1.1 (Figure 4) and 6.1.2 (Figure 5) displayed the simulated IRFs after a contractionary policy shock: the most evident conclusion from their analysis is that

[29]See, for example, Dieppe, Gonzalez Pandiella, and Willman (2012) and Christoffel, Coenen, and Warne (2010).

regardless of how much importance the CB gives to each block (or, in other words, how much the CB focuses on stabilizing the shocks from one particular block relative to the other), the single members' reactions do not change. This result is most vividly pictured by the reactions of the debt to GDP ratio and the labour income tax in both countries: they are identical in each scenario. As debt increases (due to increased interest payments to be made), the national government reacts by increasing the tax rate so to cover at least some of the increased expense. This mechanism clearly has deleterious effects in both economies, as shown by the drop in real GDP; the latter seems to stabilize around pre–shock levels slightly faster the more importance is assigned to its economy (Periphery or Core). Notably, HICP inflation exhibits an unexpected response: whereas it is well documented in the literature that the observed reaction of inflation generates the so-called "price puzzle", in this setting it is unusually large and persistent, due to the great degree of rigidities present in the model.

Apart from small differences in the time needed for the economy to stabilize back around equilibrium levels, the different weighting scenarios confirm that the two country blocks' reactions to a systemic shock do not differ: each member uses its independent fiscal policy in the same way, as the shock does not seem to hit the economies differently. This conclusion, though, should be examined under the light of the calibrated isomorphy of the two economies. The reader should, in fact, recall that most of the parameters (except for the ones governing trade, actual size of the economy and fiscal policy) were calibrated symmetrically: in other words, price and wage setting, along with all the other nominal rigidities through which monetary policy affects the economy are identical in both blocks[30]. It would indeed be interesting to ascertain the robustness of this conclusion to a more heterogeneous calibration of the model, but, for the time being, this exercise is left as a suggestion for further research.

7.2 Reactions to an idiosyncratic shock

Sections 6.1.3 (Figure 6), 6.1.4 (Figure 7) and 6.1.5 (Figure 8) portrayed the responses of both country blocks and of the CB after a sudden increase in the labour tax rate observed in the Periphery: in this case, as expected, the focus of the CB on stabilizing either economy (compared to the other) plays a central role. In fact, we observe

[30]Note that, in fact, the magnitudes of the responses across the two blocks are almost identical.

both differences in the magnitude and in the sign of the policy rate's reaction. This pronounced difference in the responses of monetary policy, in turn, has different effects on the paths to stabilization of the economies as portrayed by the reactions of GDP and HICP inflation. Both these variables, in both country blocks, exhibit negative reactions to a fiscal policy shock in the Periphery; moreover, the more importance is given to the Core by the CB, the less negative the observed reactions are.

In order to better understand the importance of the parameters φ^P and φ^C (the weight parameters in the Taylor rule), it should be kept in mind that (as outlined in the previous section) the reaction of the CB is dictated by the movement in each block's output gap, since the great degree of price rigidity makes the response of π_{Ct} and π^*_{Ct} very small. As previously described, output gap in the Periphery displays a positive deviation from equilibrium following the previously described shock, whereas output gap in the Core mirrors core GDP, displaying an almost identical negative response. Please recall that output gap (in the model) is defined as the difference between GDP and potential GDP which is unaffected by movements in the interest rate. The observed responses of output gap imply the following: since in the Periphery x_t – the output gap– responds positively to the fiscal shock, it must be the case that the response of potential GDP is *more negative* than the one of its real counterpart, which causes the observed positive deviation of GDP from its potential value. Conversely, in the Core we can observe that the responses of GDP and output gap are almost identical: this must mean that potential GDP barely responds to a fiscal shock from the Periphery.

The role of the weight parameters, again, is that of describing how much the policymakers focus on stabilizing fluctuations in each block: keeping the above discussion in mind we can now interpret the observed heterogeneity in the responses. The more weight is given to the Periphery, the more the CB will attempt to stabilize the fluctuations of x_t around equilibrium. Given the observed positive deviation, the policy rate will be hiked (i.e. the reaction of monetary policy will be contractionary) in order to close the gap, bringing it back down to equilibrium: a contractionary policy, though, does not help the recovery from an unforeseen plunge in GDP. Hence the observed sluggishness of the adjustment process in both economies (in other words, a hike in i_t depresses both output and inflation which are already below equilibrium levels due to the negative fiscal shock).

Conversely, a higher importance on stabilizing fluctuations in Core economies (high φ^C)

causes an expansionary response of monetary policy, that aims at bringing the output gap back up at equilibrium levels. The expansionary policy is clearly responsible for the smaller negative reaction as well as the faster recovery of variables in both the Core and the Periphery[31]: the policymakers, by being stimulative after the observed shock, help greatly the recovery of both economies.

To summarize, the simulated reponses suggest that if a systemic shock hits the whole CU it does not matter how important the policymakers consider each member in the conduction of monetary policy, the latters will not modify their response accordingly. On the contrary, if a shock only hits one member and then propagates to the whole union, the weights given by the CB to the stabilization of each economy are of utmost importance. In fact, the more weight is given to the economy from which the shock originates, the less expansionary monetary policy will be as a reaction: it seems that the output gap in both blocks reacts positively to a labour tax hike in the same country, hence the greater the weight on a positive deviation from trend, the less expansionary monetary policy will be. Please note that these conclusions hold for both a fiscal policy shock coming from the Periphery, as well as for the same shock coming from the Core, as shown in Appendix C.

7.3 Optimality and normative suggestions

As mentioned in the first section, optimality and normative considerations are outside the scope of this thesis for the time being; nevertheless the results can also be seen as suggesting some caution in the choice of the weighting scheme. In fact, as the responses to idiosyncratic shocks outlined, excessive focus on either member of the Union does not necessarily result in faster stabilization, but rather the opposite. Clearly, though, exogenus shocks to either member cannot be predicted by the CB, hence the results discussed above prescribe a degree of caution when attributing different importance to the single members. Namely, the CB should not focus too much on single members as an unpredicted shock could generate a recession that would be hard to emerge from in case the CB applies an extremely unbalanced weighting scheme. Note that the above does not indicate an optimal criterion for the choice of the weighting: that, in fact, is to be decided by the policymaker on the basis of his objective. In the economic

[31]Note that the difference in the magnitude of the reactions across blocks is clearly given by the fact that the adverse fiscal shock does not directly hit the core economies.

literature, many optimum criteria are based on the maximization of consumers' utility (or welfare): in the case of the ECB, it might not be the most appropriate one. In fact, the CB has declared its objective to be price stability (measured by HICP inflation) and focusing on consumer utility could be a deviation from its intended target with potential drawbacks on the institution's reputation. Keeping in mind the caution suggested by our results, two suggestions come to mind when thinking of a potential candidate for an optimum criterion: firstly, allowing time–varying weights could provide a useful tool for a rapid adjustment to shocks that hit members of the Union and hence increase the threat they represent for the aggregate stability of prices. Namely, the CB might want to shift its focus in extraordinary times given different degrees of resilience of different economies that contribute to the aggregate developents. Another suggestion lies in the synchronization of business cycles in the Euro Area. In fact, the more diversity we can observe in the business cycles across the EA, the less likely it is that the common monetary policy is optimal for all the single members. The policymaker could artificially manipulate the weighting scheme in order to achieve a higher degree of synchronization, for example by being more expansionary in order to have members that show a slower cycle "catch up" with the rest of the union. The reader is invited to keep in mind that the above is out of the scope of this thesis and that these suggestions are highly dependent on the degree of endogeneity of the modelled economy, hence the model presented previously is perhaps not the most appropriate to conduct a normative analysis of this kind. We shall leave it as a target for the future development of this work.

To conclude, the analysis of the different scenarios suggests that different weighting schemes applied by the CB only affect the stabilization path of the single members after an idiosyncratic shock that does not hit the CU uniformly. Namely, given the mechanics generated by the model, monetary policy is most expansive the less it cares about stabilizing the economy from which the shock comes. The reader is invited to consider this last fact with caution: the sign and magnitude of the responses are ultimately determined by the model and its calibration, hence they could be different in a more heterogeneous setting.

8 Limits

As was briefly mentioned in the previous sections, the presented exercise suffers from some limits, that in some cases have also been recognized by previous studies in the field.

- *Sample size*: The empirical estimation focused on describing the behaviour of the ECB in normal times. This focus constrained the sample to the period of time preceding the most recent financial crisis, namely 108 observations for each variable of interest. In light of this scarcity, a conservative approach in the estimation of the reaction function was preferred to a more articulated specification as to ensure the most accurate estimation. Clearly, the sample could have been increased, had the conduction of monetary policy in extraordinary times (i.e. when the policy rate is constrained by the effective lower bound, as was the case during the crisis) been included. Nonetheless, this further expansion, for the time being, is left for further development of this exercise in the future.

- *Empirical Estimation of the Taylor Rule*: As was mentioned in Section 2, a growing body of literature has turned its attention to the modelling of the observed nonstationarity of the interest rate. This was done by lifting the assumption of a symmetric response of the CB to positive and negative deviations of the variables of interest from their intended target. Whereas this is certainly a more realistic representation of the behaviour of policymakers, the sample size utilized in this thesis could prove to be a serious limitation, for example, when further restricting it to find the threshold during the estimation of a Threshold Autoregressive Model (TAR). As mentioned above, different augmentations of the Taylor rule were deemed unfeasible within the conservative framework imposed by data availability: given a wider sample size, they could be implemented in a more precise reaction function.

- *Modelling a currency union*: The open economy DSGE model used in this analysis is indeed well suited in this context; the major limitation it has derives from the symmetric calibration of the two country blocks. In fact, as mentioned in the previous section, the results obtained from the scenario analysis could have been different if the calibration had reflected more individual characteristics pertaining to each block. This task, although, would be a rather daunting one, keeping in mind the great number of aspects that should be calibrated to reproduce the actual dynamics of core and peripheral EA economies. Whereas it is most certainly an appealing road to take, the computational burden and access to a wide range of data it requires did not make it a feasible objective in the scope of this analysis. Nevertheless, the model present the following features that make it the appropriate choice for the conduction of this analysis: firstly, it embeds a number of rigidities that have widely been recognized in the literature as necessary to produce good fitting results. Secondly, it features an open economy dimension that is most apt at describing the pecuiar framework of the EA. Lastly, the division of the blocks in Core and Periphery is appropriate, also on the basis of fiscal policy considerations such as the level of government debt to GDP ratios and the reaction to its movements (please refer to the original work for further tractation).

9 Conclusion

In this thesis, the relative importance of members of a currency union in the conduction of monetary policy was analyzed: the purpose was to ascertain what differences would emerge if the ECB, instead of weighting each member by its economic size in the union, were to give different importance to each member states. To address this question, both an empirical and a theoretical framework were employed: firstly, the behaviour of the ECB was modelled on available data, spanning from 1999:01–2007:12. Then, the obtained estimates were embedded in the model developed by Erceg and Lindé (2013), which was used to simulate the responses of the Member States – divided in two country blocks, Core and Periphery – to both a systemic shock and an idiosyncratic shock.

The empirical estimation of a reaction function was conducted in a standard way, by using the Generalized Method of Moments to obtain point estimates for the coefficients of a Taylor rule: notice that the dataset covers the period from Stage Three of the European Monetary Union (when the ECB started exerting its sovereignty) until before the most recent crisis. In accorance with the literature, and with the policy rule used by Erceg and Lindé, the interest rate has been modelled as reacting to deviations of HICP inflation from its intended target and to movements in the output gap, defined as percentage deviation of real GDP from its trend. The results of the estimation are all significant at least at the conventional 95% confidence level and confirm that the ECB has indeed acted to stabilize HICP inflation around roughly 2% (as outlined in the quantitative definition of price stability given by the ECB) and that it also responds to fluctuations in real economic activity (one of the two pillars, together with monetary analysis). The most appropriate leads for the expected values of HICP inflation and output gap were chosen with the AIC and SBIC criteria, and the chosen set of instruments was confirmed as valid by the Hansen's J–test of overidentifying restrictions; moreover, the estimation is robust to the use of industrial production as an alternative measure of economic activity and to the exclusion of Slovenia from the aggregation of EA variables[32].

The estimated parameters were then used in the aforementioned DSGE model, which was slightly altered to allow for a discrepancy between the actual economic weights of the two blocks and the weights given by the CB. Moreover, the fiscal policy reaction function was allowed to differ between the two blocks[33] so that the Core displays a smoother adjustment to monetary policy whereas the Periphery reacts aggressively; the rest of the calibrated parameters were left as in the original work. As previously mentioned, the responses to two simulated shocks were analyzed: the former, systemic shock was simulated as a contractionary monetary policy shock whereas the latter, an idiosyncratic shock, was simulated as a labour income tax hike in the Periphery.

To observe the effect of different weighting schemes in the policy rule, five scenarios were simulated: the "Baseline" scenario, where the policy weights and the actual economic weights coincide, the "Equality" scenario, in which the weights within the Taylor rule are equal, two extreme scenarios, namely "Importance to Core" and "Importance to Periphery", which gave extreme importance (90%) to each respective block in the conduction of monetary policy and lastly one scenario, "Germany as Core", that assumed the Core block to be composed of only Germany.

The simulations outline the following main results: firstly, the blocks' responses to a systemic shock are mostly insensitive to the relative weighting of the blocks within the reaction function. Namely, both blocks will always react in the same way to a

[32]Since Slovenia only enters the sample for the last 12 periods, it could have caused a biased estimation of the actual coefficients by inducing a "fictitious" increase in aggregate output.

[33]The reader should recall that the two economies were calibrated to be isomorphic in most of their aspects.

contractionary monetary policy shock, regardless of how much the attention of the CB is focused on each block. Secondly, the reactions of both the CB and the blocks to an idiosyncratic shock are different, depending on the importance given by the policymaker to the block in which the shock originates. Namely, in all scenarios that simulate an idiosyncratic shock, monetary policy is most expansionary the least it cares about the stabilization of the economy in which the shock generates.

Clearly, this analysis presents some limits deriving from the infeasibility to implement some features while keeping the dimension of the study tractable; namely a more heterogeneous calibration of the model and a more complex representation of the policy reaction function. Nonetheless, the results outline some interesting dynamics that would be meaningful to analyze in a more complete setting. Therefore, what this study represents is an initial suggestion for further research in this direction.

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Appendix A

A.1 The econometric approach: Generalized Method of Moments

GMM was chosen as the instrument for the empirical estimation on the basis of the strong theoretical grounds and practical advantages outlined by the large body of literature on Taylor rule estimation. For the reader's convenience, we repeat Equation (1) below, so to describe its characteristics that made GMM the chosen method for estimation.

$$i_t = (1-\rho)(R + \gamma_\pi(E_t[\pi_{t+k}|\Omega_t] - \pi^*) + \gamma_x E_t[x_{t+j}|\Omega_t]) + \rho i_{t-1} + \epsilon_t \tag{1}$$

As previously mentioned, the above formulation enables taking into account two fundamental aspects of policymaking that the original formulation of the rule neglected to. Namely, the forward-looking behavior of the CB and the wide set of information that the policymakers have as compared to the variables to which mechanical reactions are observed are captured by the terms $E_t[\pi_{t+k}|\Omega_t]$ and $E_t[x_{t+j}|\Omega_t]$. The expectations operator conveys the forward-looking stance of monetary policy in that, as was described in the previous sections, due to the lag in the transmission of monetary policy and due to the assumption of rational expectations of economic agents, the policymakers must be forward looking in their decision. The available information set at the present time, Ω_t, perfectly captures the wide information set that is available to the policymaker when decisions are taken. Recall, in fact, that the ECB targets price stability not only by keeping inflation rate as close to target as possible, but also by taking into consideration further information on the basis of the two pillars approach. This, in practice, translates to the estimation of an *overidentified* system, i.e. the reaction to two key variables is being evaluated on the basis of a wider set of information, namely there are more variables than parameters to be estimated.

A.2 The GMM estimator and moment conditions

GMM is an estimation method that nests other popular methods within itself: in fact Ordinary Least Squares (OLS) , Instrumental Variable (IV) and Two-Stage Least Squares (2SLS) estimators can be shown to be particular cases of the GMM one. As mentioned above, GMM enables the estimation of parameters of an overidentified system based on some moment conditions that are defined by the theoretical model employed: hereby follows a short description of the estimator and moment conditions[34].

Let us consider the simple regression model

$$y_t = \theta X_t + u_t$$

Where y_t is the dependent variable, θ is a vector of parameters, X_t is a vector of explainatory variables and u_t is the residual term. Let us introduce a vector of instruments, Z_t, such that they are exogenous, namely

$$E[Z_t u_t(\theta)] = 0$$

where $u_t(\theta) = y_t - \theta X_t$

The *moment function* for this model is the following:

$$g(w_t, \theta) = E[Z_t'(y_t - \theta X_t)]$$

The set of moment conditions is derived from the theoretical assumption of the model: in this simple case, the assumption is that the instruments are uncorrelated with the residual term. Hence, the set of moment condition is described by the set of orthogonality conditions

$$g(w_t, \theta) = E[Z_t'(y_t - \theta X_t)] = 0$$

Note that, in the case of an exactly identified model, all the conditions implied by the above equation hold with equality (recall: exactly identified means that there are

[34] The description will only focus on a simple regression model, as to give the reader an explaination on the reasons for the practical use of GMM in this context. A more complete tractation can be found in Hall (2005), Hayashi (2000), Chapter 3 and Hamilton (1994) Chapter 14.

exactly many instruments as there are parameters to be estimated, in other words Z_t and X_t are of equal length). In the case of an overidentified system, instead, there cannot be a unique solution to the above conditions. Hansen (1982) proposed to solve this problem by minimizing the distance of the set of moment conditions from its expected value of 0, as there is no unique value of θ for which the above holds. Namely, let us define the function

$$Q_T(\theta) = T^{-1}\sum_{t=1}^{T} g(w_t,\theta)'\ W_T\ \ T^{-1}\sum_{t=1}^{T} g(w_t,\theta)$$

where T represents the sample size. Alternatively, in matrix notation, we have

$$Q_T(\theta) = [T^{-1}\ u(\theta)'Z]\ W_T\ [T^{-1}\ Z'u(\theta)]$$

a quadratic form that describes the distance of the relevant moment conditions from their expected value of 0. The GMM estimator is defined as:

$$\hat{\theta} = argmin_\theta\ \ Q_T(\theta)$$

Namely, the GMM estimator is the parameter vector $\hat{\theta}$ that makes it so that the moment conditions are as close as possible to zero.

The term W_T in the expression for Q_T is a *weighting matrix* that is of pivotal importance in the estimation as it assigns some weight to each of the moment conditions. Since there is no value of the parameter vector that will satisfy the equality constraint imposed by the moment conditions, the weight matrix assigns different importance to each of the conditions to be set as close as possible to zero.

The GMM estimator takes the following form (i.e. as the result of the above minimization):

$$\hat{\theta}^{GMM} = [(T^{-1}X'Z)W_T(T^{-1}Z'X)]^{-1}(T^{-1}X'Z)W_T(T^{-1}Z'y)$$

A.3 The weighting matrix and 2SLS

The choice of the weighting matrix W_T is crucial towards the estimation of the parameters contained in θ, as the data do not provide any information about it. Let us take a simple example: if the matrix is chosen so that $W_T = (T^{-1}Z'Z)^{-1}$, then the GMM estimator becomes

$$\hat{\theta}^{GMM} = [(T^{-1}X'Z)(T^{-1}Z'Z)^{-1}(T^{-1}Z'X)]^{-1}(T^{-1}X'Z)(T^{-1}Z'Z)^{-1}(T^{-1}Z'y)$$

which is none other that the 2SLS estimator $\hat{\theta}^{2SLS}$. If the system is instead exactly identified, the weighting matrix plays no role and the GMM estimator collapses to the IV estimator[35] $\hat{\theta}^{IV}$.

It can be shown that the optimal choice for the weighting matrix is, in practice, the inverse covariance matrix of the moments, i.e.

$$S^{-1} = (Var[T^{-1}\sum_{t=1}^{T} z_t u_t(\theta)])^{-1} = (T^{-1}E[u(\theta)^2 Z'Z])^{-1}$$

which generates the GMM estimator with the least asymptotic variance; in other words this choice of the weighting matrix generates the most stable results. There are two observations that should be kept in mind on the estimation and on the form of the weighting matrix:

1. *Estimation* : As is clear from the above formulation, the estimation of S depends on the vector of parameters θ. How to estimate, then, the weighting matrix? There are three main approaches:

- 2SGMM or *two-stage GMM estimator*: An initial guess for the weighting matrix ,$\hat{S}^{-1}$, is used to obtain a first estimate of $\hat{\theta}$. Then, the newly obtained estimate of the parameter vector $(\dot{\hat{\theta}})$ is used to obtain the weighting matrix S^{-1}. Typically, the initial guess $\hat{S}^{-1}$ is the weighting matrix that produces the 2SLS estimator.
- ITGMM or *iterated GMM estimator*: The 2SGMM process is iterated a number of times until a convergence criterion is met. For example, the different between an estimated vector of parameters $\hat{\theta}_i$ and the one obtained from the successive

[35]Please note that a more thorough tractation can be found in Hall (2005). These sections only aim at providing the reader with an explaination on the choice of GMM as opposed to 2SLS as an estimation method.

iteration, $\hat{\theta}_{i+1}$, is smaller than an abitrarily small value e. Namely, $|\hat{\theta}_{i+1} - \hat{\theta}_i| < e$

- CUE or *continuously updating GMM estimator*: in this case, the vector of parameters and the weighting matrix are estimated simultaneously. In practice, within the minimization, the weighting matrix is treated as a function of the parameter vecrot θ : the minimization looks like the following

$$\hat{\theta} = argmin_{\theta}\ [T^{-1}\ u(\theta)'Z]\ W_T(\theta)\ [T^{-1}\ Z'u(\theta)]$$

It has been shown that this estimator yields more reliable results than the previous ones, especially in small samples.

2. *Form of the weighting matrix* : As was shown above, for a particular choice of the weighting matrix, the GMM estimator is identical to the 2SLS estimator. This derives from a particular assumption on the error terms: namely, if the errors are homoskedastic and there is no autocorrelation the GMM estimator reduces to the 2SLS estimator. Recall, in fact, that the optimal weighting matrix was given by $W_T = (T^{-1}E[u(\theta)^2 Z'Z])^{-1}$. If the error are homoskedastic and non-autocorrelated, the above simplifies to $W_T = (T^{-1}\sigma_u^2 E[Z'Z])^{-1}$, which corresponds to the weighting matrix that generates the 2SLS estimator. Hence, GMM and 2SLS are indentical *under the assumptions of homoskedasticity and non-autocorrelation of the residuals* which can sometimes be quite restrictive assumption. In case of heteroskedasticity and autocorrelation of the residuals, GMM yields better estimation results.

Appendix B : IRFs comparison by scenario

Please note that as the reactions of the two blocks are insensitive to their weighting in the Taylor rule in the case of a systemic shock, only the “Baseline” scenario is shown below for that case.

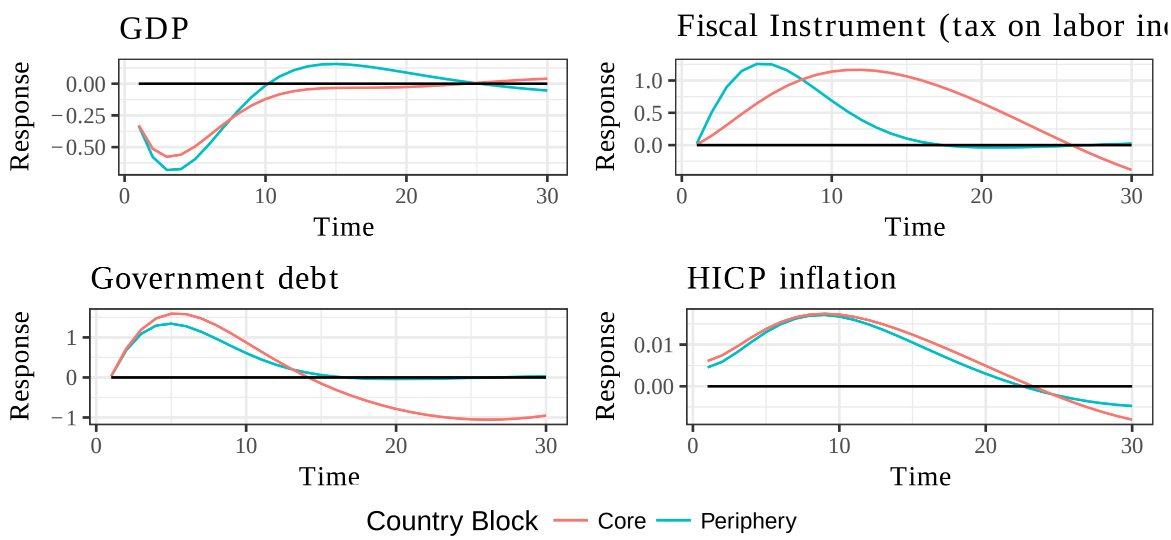

Figure 9: Policy shock: Baseline scenario responses

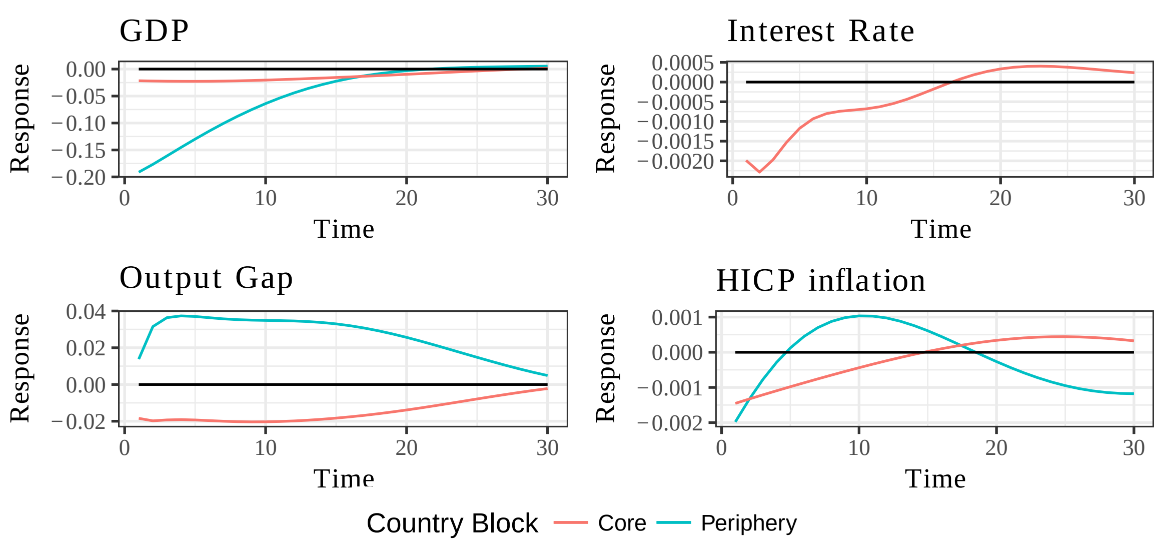

Figure 10: Periphery fiscal policy shock: Baseline scenario responses

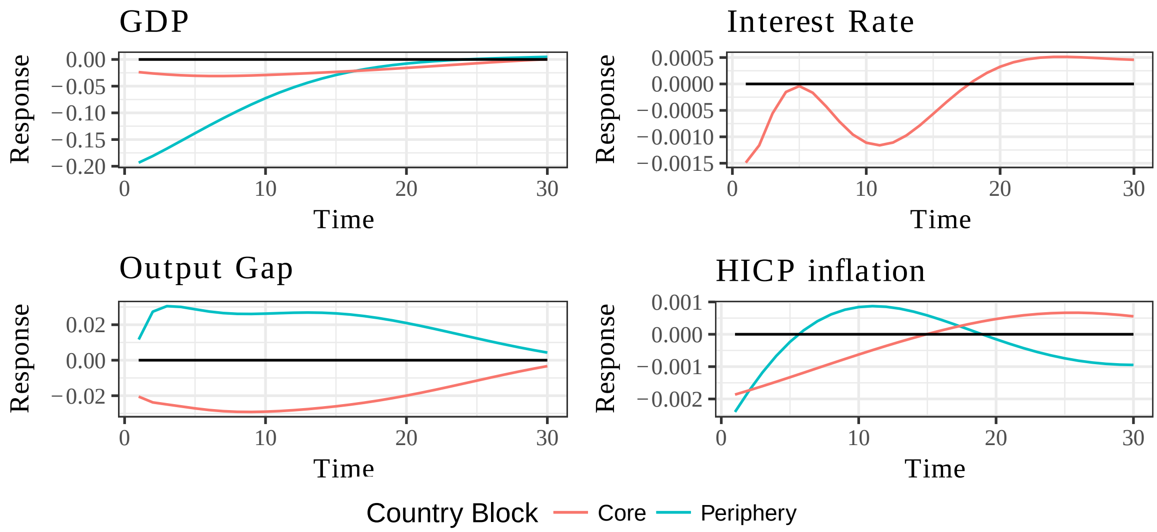

Figure 11: Periphery fiscal policy shock: Equality scenario responses

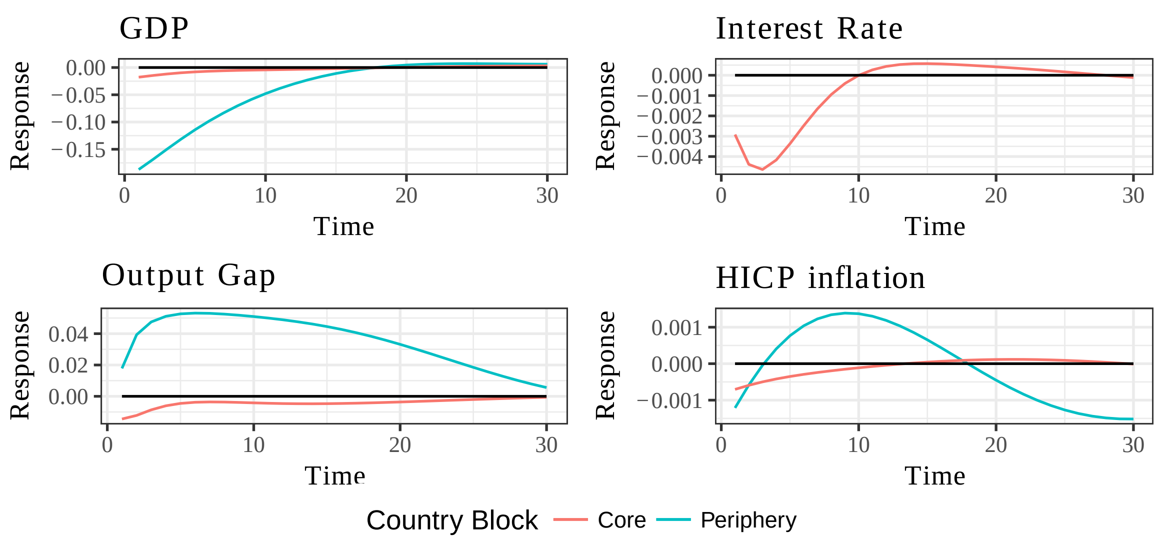

Figure 12: Periphery fiscal policy shock: Importance to Core scenario responses

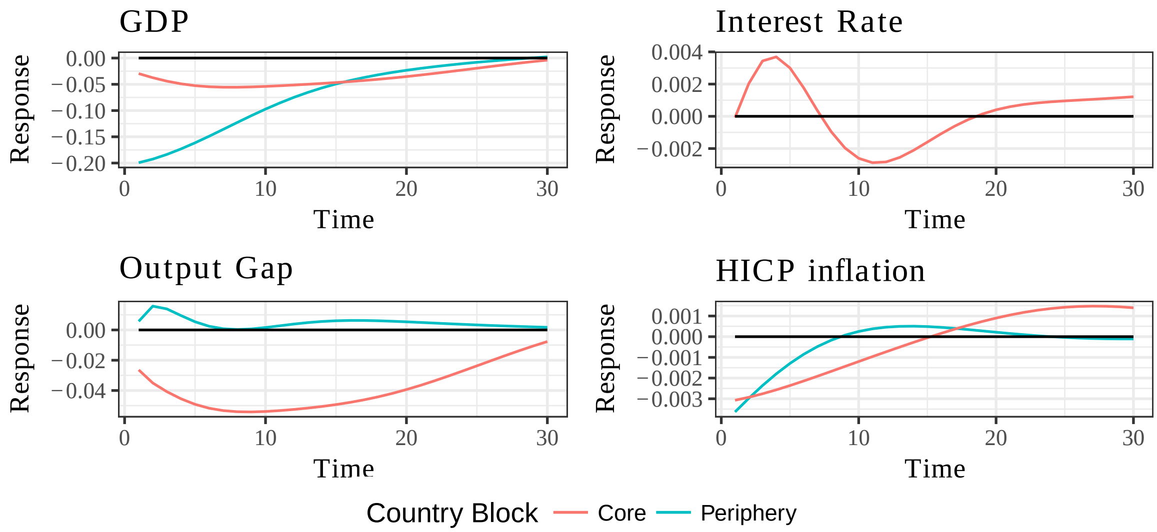

Figure 13: Periphery fiscal policy shock: Importance to Periphery scenario responses

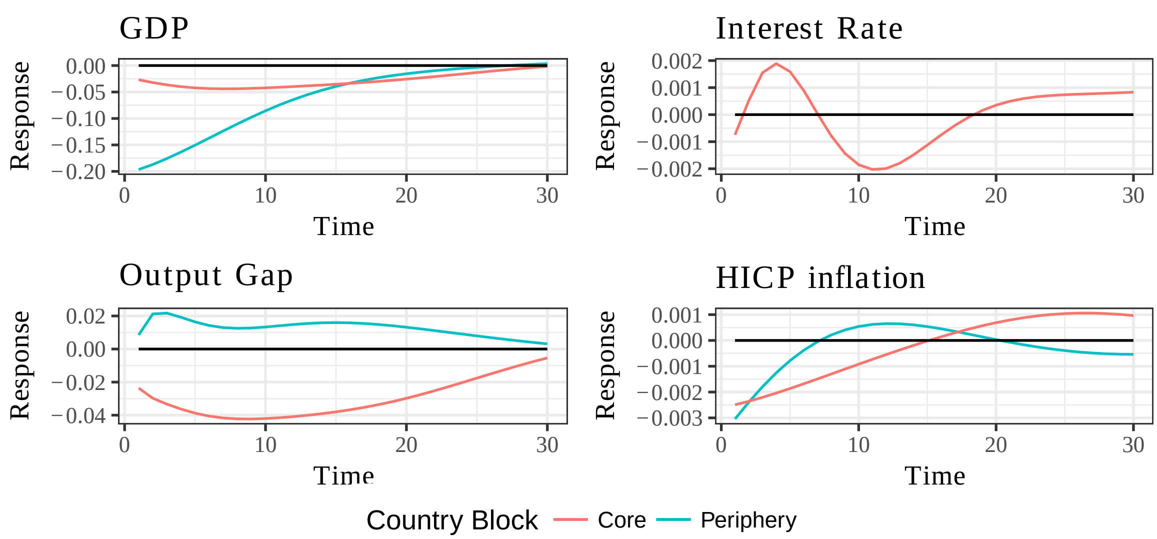

Figure 14: Periphery fiscal policy shock: Core=Germany scenario responses

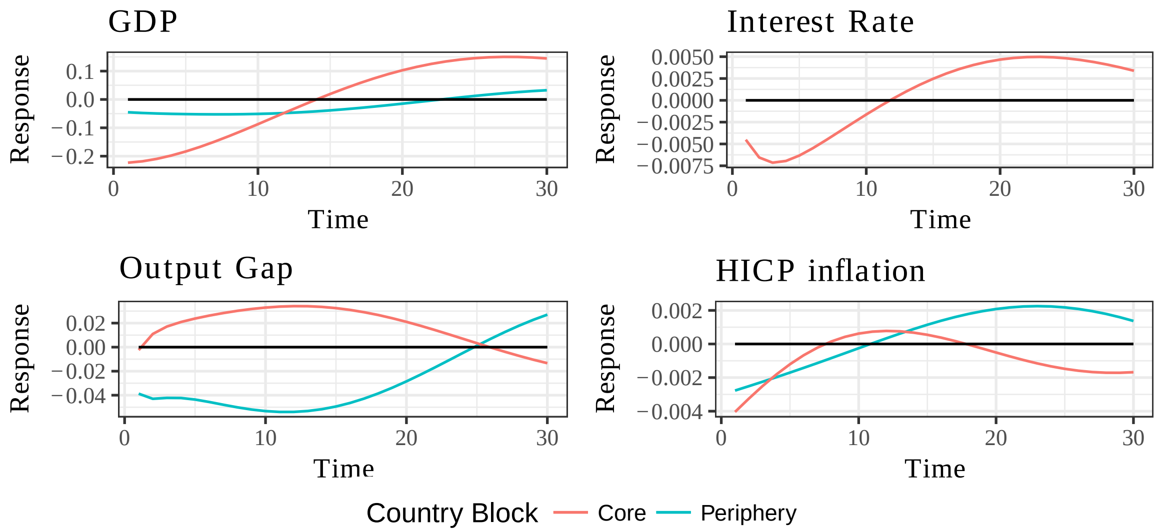

Figure 15: Core fiscal policy shock: Baseline scenario responses

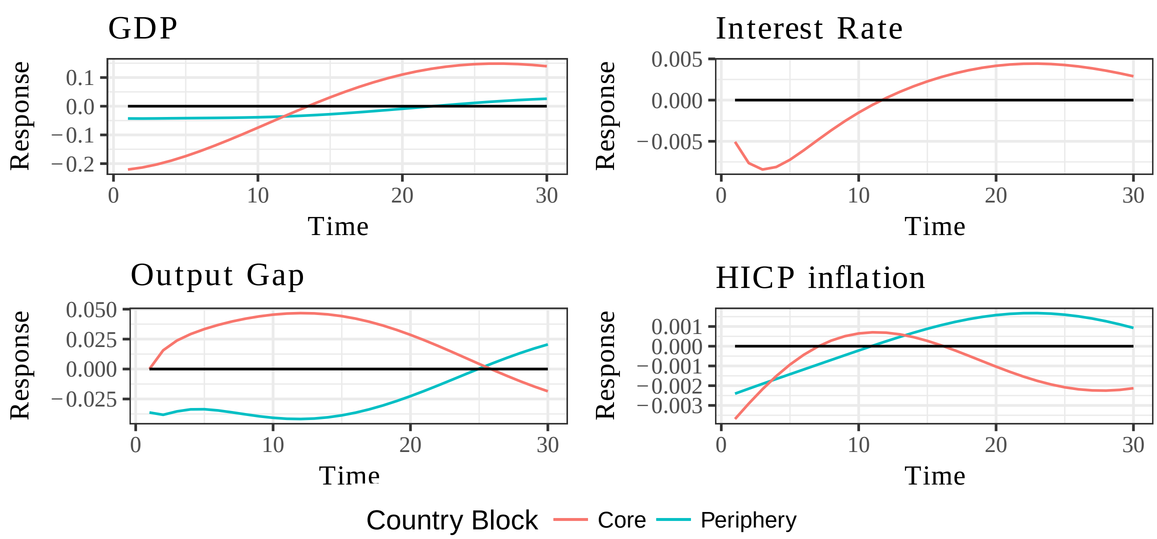

Figure 16: Core fiscal policy shock: Equality scenario responses

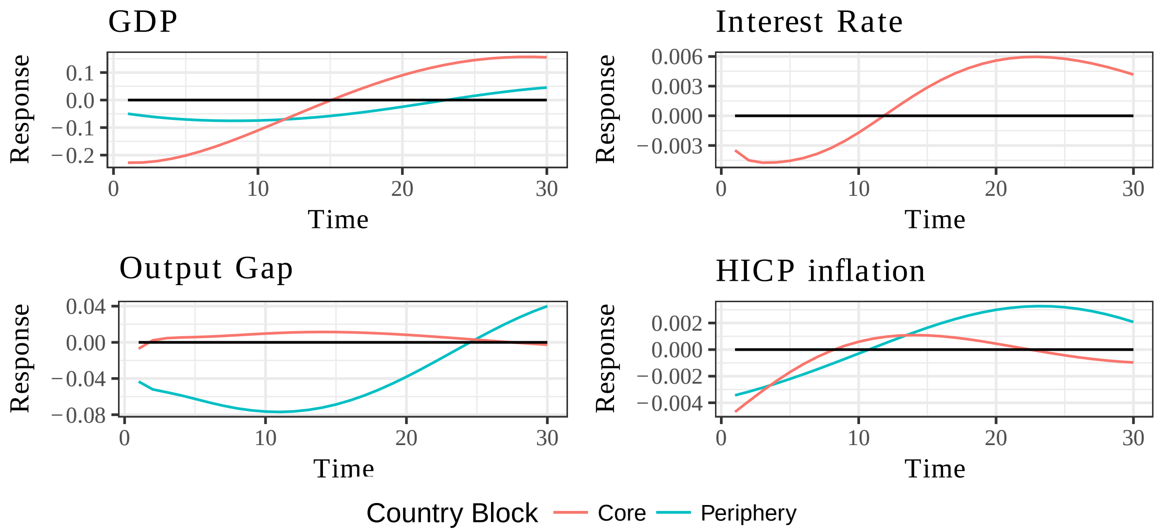

Figure 17: Core fiscal policy shock: Importance to Core scenario responses

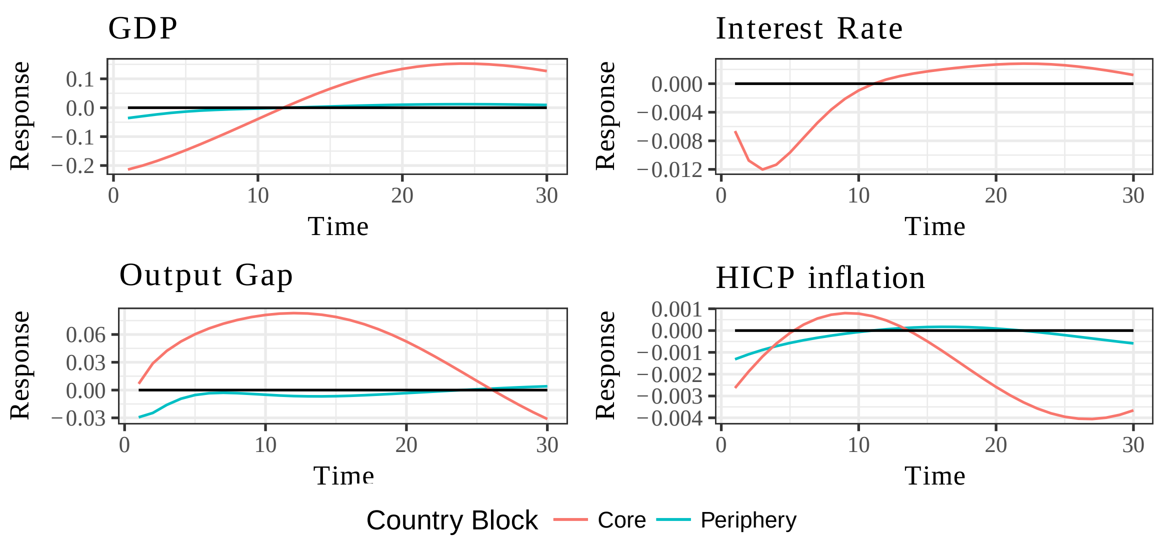

Figure 18: Core fiscal policy shock: Importance to Periphery scenario responses

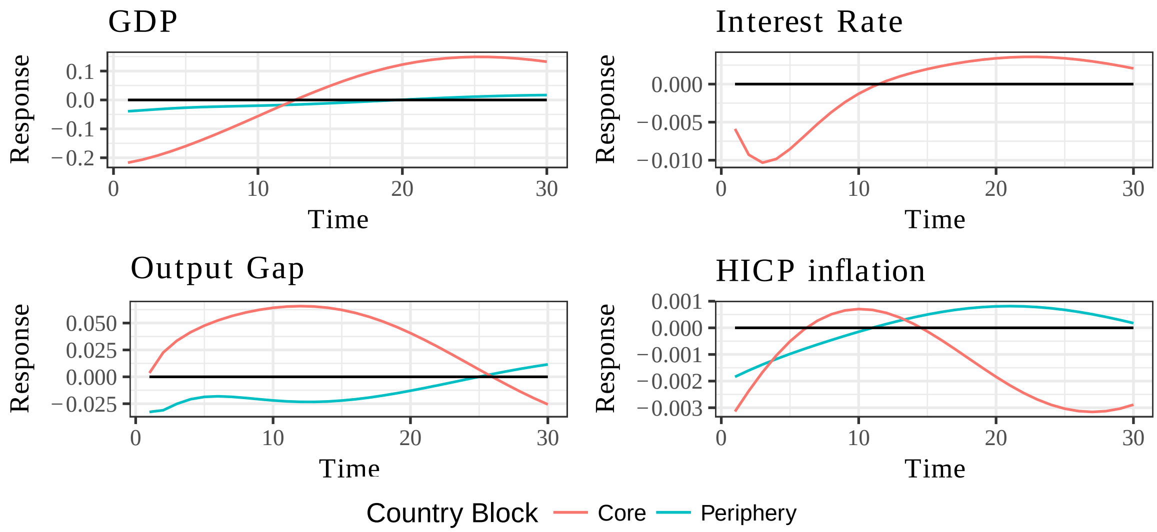

Figure 19: Core fiscal policy shock: Core=Germany scenario responses

Appendix C : responses to a fiscal shock in the Core

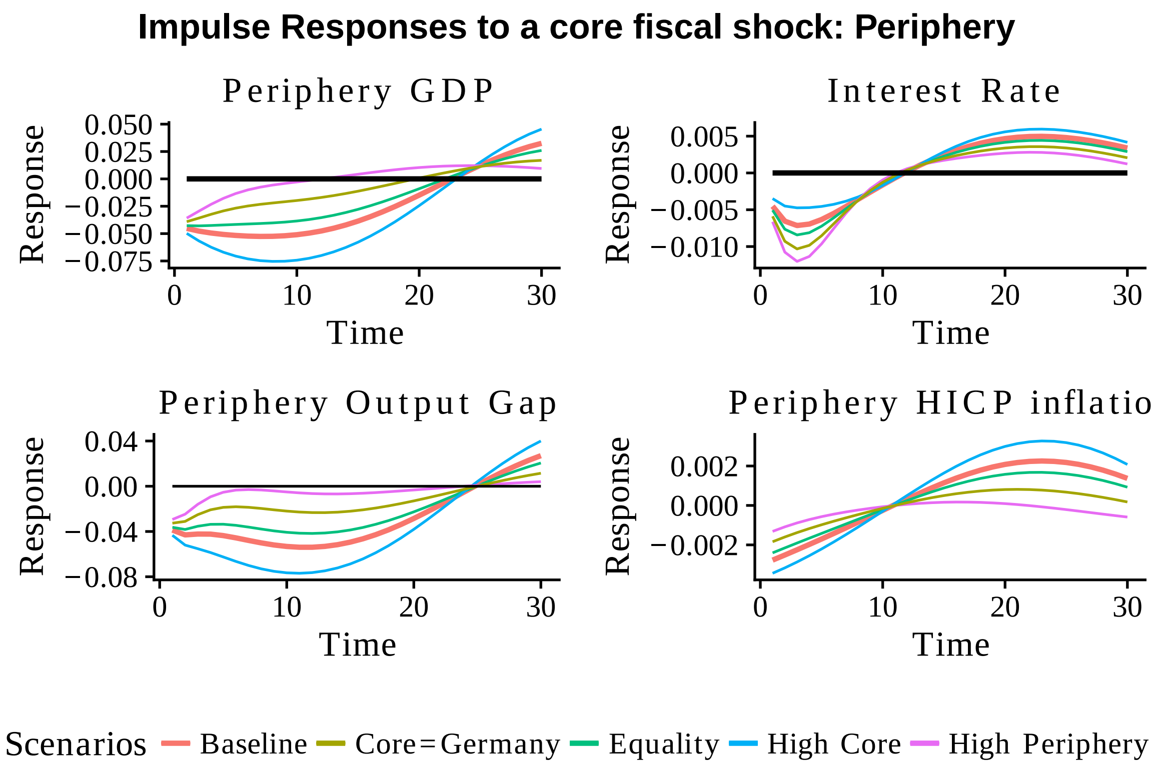

Figure 20: Periphery responses to a core fiscal shock

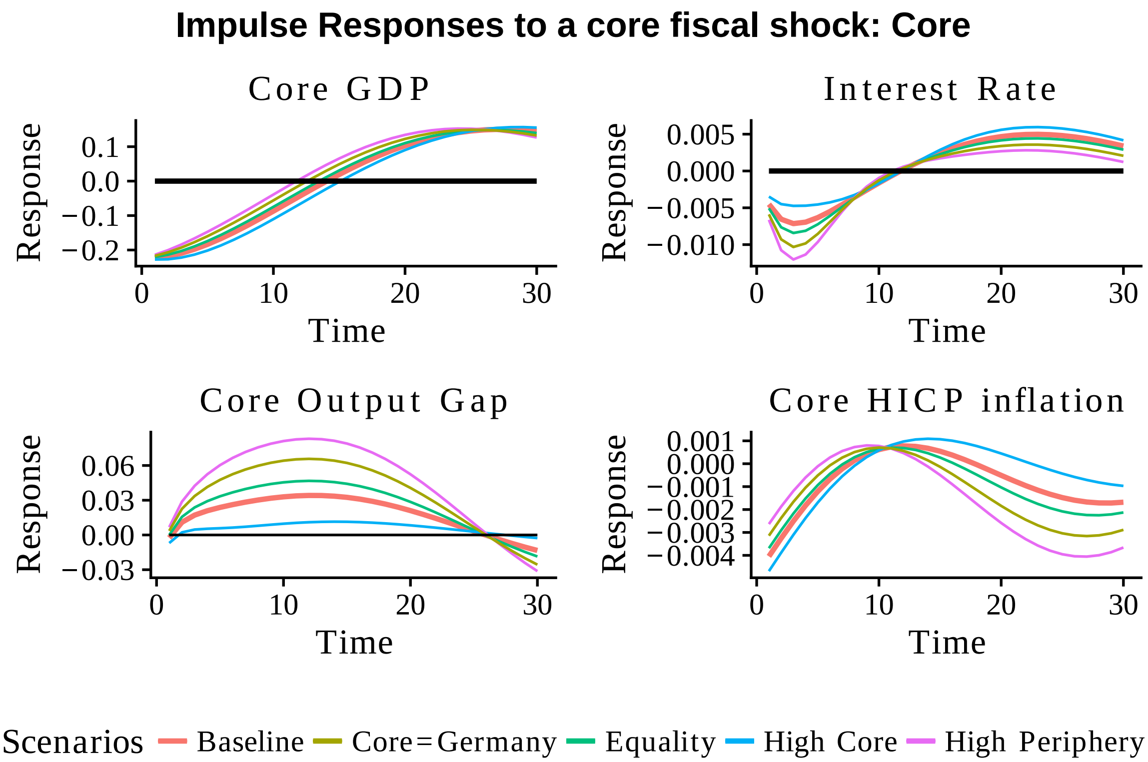

Figure 21: Core responses to a core fiscal shock

The conclusions outlined in Sections 5 and 6 seem to hold also for an idiosyncratic shock generated in the Core: the higher the importance on the core, the less expansive the CB will be, hence the slower the recovery to pre-shock levels in both economies.