Department of Economics

Athens University of Economics and Business

WORKING PAPER no. 15-2023

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September 2023

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Does Agents' learning explain deviations in the Euro Area between the Core and the Periphery?*

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Abstract

In this paper we investigate the role of learning in a two-country, dynamic stochastic general equilibrium (DSGE) model to analyze the differences in the economic cycles between the Core and the Periphery in the Euro Area for the period 2000 to 2019. Following Milani (2007) we compare the performance between rational expectations (RE) models with New-Keynesian frictions (price, interest rate and wage stickiness) and habits with models augmented with learning using Bayesian techniques. By incorporating learning, we aim to capture the impact of the endogenous evolution of beliefs in the two economies. Our findings suggest that learning plays a significant role in explaining the divergent economic performances of the Core and the Periphery. Furthermore, we conclude that a monetary authority who aims to minimize welfare losses from output and inflation volatility should react more intense to stabilize inflation under learning.

JEL classification: C10; D84; E30; E50; E52

Keywords: Expectations; Constant-gain learning; Persistence; Habit formation; Inflation inertia; Wage inertia; New-Keynesian model.

*Mavrigiannakis gratefully acknowledges financial support from the Greek State Scholarships Foundation (IKY), co-financed by Greece and the European Union (European Social Fund-ESF) through the Operational Programme ≪Human Resources Development, Education and Lifelong Learning≫ in the context of the Act "Enhancing Human Resources Research Potential by undertaking a Doctoral Research" Sub-action 2: IKY Scholarship Programme for PhD candidates in the Greek Universities. We thank Petros Varthalitis for comments and suggestions.

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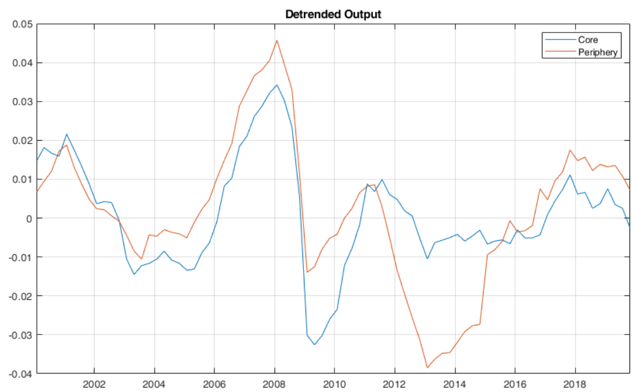
1 Introduction

The boom (2000-2008) and subsequent bust (2009-2015) experienced by the Peripheral economies of the Eurozone (Italy, Spain, Greece, Portugal, and Ireland) stands out as one of the most remarkable and intriguing episodes in recent economic history among developed nations. Figure 1.1 illustrates the evolution of cyclical output between the two Areas. Even though both areas of the Eurozone have experienced the same pattern in their cycles, before and after the global financial crisis of 2008, it can be noticed that the amplitude of the cycle is more intense in the Periphery.

Figure 1.1: Evolution of the cyclical output of Core and Periphery.



Source: OECD and authors' own calculations. The series on output of each area have been constructed by adding the gdp of the Core countries (Austria, Belgium, Finland, Germany, France and Netherlands) and Periphery countries (Greece, Ireland, Italy, Portugal, Spain) considered in our work. The trend has been removed using HP filter, as it is standard in the literature.

The related literature has attributed the causes of the discrepancy in the amplitude of the business cycles between Core and Periphery mainly to two fundamental reasons. First, the financial integration within the Eurozone, favoured increased capital flows and cross-border borrowing, resulting in lower interest rates for the Peripheral economies. As a result, these countries experienced increased borrowing, rapid credit expansion, and gradual accumulation of external imbalances. This led to a deterioration of the government debt and possible asset bubbles. When economic conditions deteriorated, these imbalances became more pronounced, leading to a sharp contraction and financial distress (see Cesaroni and Santis (2015); Honohan and Leddin (2006) and Blanchard (2007)).

Second, some authors (for instance, De Grauwe and Ji (2016) and Belke et al. (2016)) have discussed that the Peripheral economies responded more intense to area-wide shocks compared to the Core economies, which led to more pronounced economic fluctuations. De Grauwe and Ji (2016) observe that this assymetry led to a situation where the Periphery experienced an unsustainable boom, characterized by increases in wages and prices at a higher pace compared to Core, resulting in a decrease in competitiveness due to higher relative unit labor costs. Moreover, the boom in the Periphery was occasionally accompanied by asset price bubbles. When the global economic crisis of 2008 occurred, countries of the Periphery were severely hit, having the need to further implement internal devaluations to improve their competitiveness. This introduced deflationary forces, increasing unemployment and requiring the implementation of austere fiscal measures to tackle the high government debt accumulated during the boom.

Behavioral factors behind the boom-bust cycle in the Eurozone have been acknowledged in the literature (Blanchard (2007)), but their analytical examination remains limited. For instance, Blanchard explains that expectations of faster growth were one of the factors contributing to the boom experienced by Portugal in the early 2000s. Additionally, studies such as the work of (Milani (2007)) have shed some light on the role of learning in explaining the evolution of macroeconomic variables. By implementing a model with habits, price and interest rate indexation, Milani demonstrates that when agents are allowed to learn, the mechanical sources of persistence observed in many macroeconomic variables are no longer necessary. These findings suggest that learning can contribute to explaining the dynamics of macroeconomic variables.

We contribute to the related literature by shedding light on whether bounded rationality, as modeled by learning (Evans and Honkapohja (2001)), helps to explain the discrepancy in the amplitude of the business cycles between the Core and Periphery. For this scope, we develop two two-country dynamic stochastic general equilibrium (DSGE) models in a New-Keynesian framework. The first model includes the basic New-Keynesian structure with capital, plus wage stickiness, whereas the second is further augmented with additional frictions, including price indexation, interest rate stickiness, as well as habit formation. We examine both models using rational expectations and compare their results with the respective models with learning, following the work of Milani (2007). The models are calibrated and estimated using Bayesian techniques. Our findings suggest that learning fits better the data, without the need of the additional sources of persistence, in line with the findings of Milani. Moreover the constant gain value, which is estimated jointly with the other parameters, indicates that agents of Core learn at a faster pace in comparison to agents of the Periphery, providing a new channel of explanation considering the observed differences in the magnitude of business cycles between the two areas of the Eurozone. Finally, we show that the monetary authority should react more decisively to tackle inflation under learning, in line with the findings of Orphanides and Williams (2008) and implications provided in Chortareas et al. (2012).

The rest of the paper is organized as follows. Section 2 provides a review of the relevant literature on DSGE models with learning and the differences between the Core and the Periphery. Section 3 analytically presents our modeling approach. Section 4 discusses the data sources, the estimation procedure, and the empirical strategy. Section 5 presents the empirical findings and their implications.

Section 6 discusses the robustness of our findings under alternative assumptions. Finally, section 7 concludes our findings.

2 Related literature

In the context of the Euro-Area there is a growing literature that recognizes the discrepancy in the business cycles between Core and Periphery. Belke et al. (2016) examine business cycle synchronization in the Eurozone with a special focus on the core-periphery pattern in the aftermath of the crisis. Using panel data analysis, their estimations suggest that countries of the Core are faced with increased synchronization among themselves after 2007Q4, whereas peripheral countries decreased synchronization with regards to the Core. De Grauwe and Yuemei (2018) emphasize the asymmetry in the amplitudes of the same cycle between Core and Periphery, highlighting the policy challenges that the monetary and fiscal authorities face, arguing in favor of a common fiscal insurance mechanism in the Eurozone.

Rational expectations hypothesis (REH) is the dominant approach for modeling expectations in DSGE models, assuming perfect foresight given all available information. REH provides model-consistent expectations and has been widely used in the literature on empirical DSGE models. There is a growing literature that studies whether departing from the REH can help explain observed economic phenomena that can be attributed to behavioral attributes of economic agents. The notion for departing from the REH, stems from the idea of bounded rationality as described, among others, from Sargent (1993). One way to model bounded rationality, is the learning approach of Evans and Honkapohja (2001), which deviates from full rationality in a moderate way. According to this, agents are bounded rational in the sense they may not know the correct relations between the variables of the model; however, they are allowed to use the available data and to continually update their expectations, taking into account their forecasting error.

Incorporating bounded rationality in stochastic general equilibrium (DSGE) models has been introduced relatively recently in the related literature. For instance, Orphanides and Williams (2008) demonstrate that optimal policy derived under the assumption of rational expectations can perform poorly when expectations deviate modestly from the REH. Furthermore, they show that the optimal control policy can be made more robust by deemphasizing the stabilization of real economic activity and interest rates relative to inflation in the central bank loss function. De Grauwe (2012) shows that animal spirits, i.e. waves of optimism and pessimism, have a self-fulfilling property and can drive the movements of investment and output.

Based on learning, Milani (2007) examines expectation shocks in a near-rational expectations environment, using a simple three-equation New Keynesian model and constant gain learning. He shows that learning has a great role as driver of business cycles of the US. A key feature of his work, which we include in our analysis, is that by comparing learning with a benchmark model with rational expectations and various additional sources of persistence, he shows that a simple model which incorporates learning, better fits the data. We perform a respective analysis for the case of the Euro Area. Moreover, in a similar set, Milani (2009) implements a simple monetary DSGE model with learning for the Euro Area, including some structural sources of inertia, such as habit formation in consumption and inflation indexation. Bayesian methods are used to estimate the agents' beliefs jointly within the system. He concludes that the learning process in Europe is slow leading persistence to remain relatively stable over time.

Ormeño and Molnár (2015) use survey data to estimate and compare the performance of a learning model with a benchmark model with rational expectations. They add information from observed inflation expectations to discipline the estimation of models with learning. They conclude that the predictive power of their benchmark model is improved when augmented with both survey data and learning. Bullard et al. (2008) investigate whether judgemental adjustment may lead to the possibility of self-fulfilling fluctuations, showing that "exuberance equilibria" may exhibit considerable volatility relative to the rational expectations equilibrium. Their findings suggest that "sunspot-like" equilibria can exist, without requiring assumptions such as indeterminacy, indicating that policymakers should take into account the risk of exuberance equilibria and design appropriately their policies to tackle this phenomenon. Slobodyan and Wouters (2009) evaluate the empirical performance of a medium–scale DSGE model where agents form expectations about forward variables by using small forecasting models, in particular AR and VAR forecasting models through Kalman filter estimation. The results provide evidence that a model in which agents use a mixture of simple forecasting models to form expectations, does fit the data of US. better than the full rational expectations model. Eusepi and Preston (2011) examine learning dynamics as a source of economic fluctuations, assessing its implications for the amplification and propagation of technology shocks in real business cycle models. They conclude that first, learning improves model fit relative to rational expectations and second, an augmented model, consistent with expectations-driven business cycles, resolves co-movement problems of variables and produces additional amplification and propagation, requiring 30 percent smaller technology shocks than a benchmark model with rational expectations, outperforming it using second-order moments analysis. We use their technique in calibrating the constant gain term, as robustness for our analysis.

Milani (2017) moves a step forward to examine whether expectation shocks, "sentiments" as he defines them, make agents deviate their expectations from those implied by the constant-gain, learning model. These deviations capture excesses waves of optimism and pessimism. He concludes that exogenous variations in sentiments are responsible for a significant portion of U.S. business cycle fluctuations. Cole and Milani (2019) aim to test the capability of New Keynesian models to match the data by comparing different DSGE-VAR models. They conclude that a basic model which embeds the REH fails to capture the co-movements between observed macroeconomic expectations and realizations. On the opposite, when REH is relaxed, they find that the model's performance to fit the data improves considerably, highlighting the role of adding into the learning mechanism sentiment or expectation shocks, as sources of aggregate fluctuations.

Another strand of literature focuses the role of news, mostly about future technology, as sources of fluctuation. Within this strand, Beaudry and Portier (2006) explain that news about future technological opportunities causes a demand boom that precedes productivity growth by a few years, explaining about 50% of business cycle fluctuations. Inspired by this work, Fujiwara et al. (2011) allow news shocks on the total factor productivity, and estimate their medium-scale DSGE model using Bayesian methods for the US. and Japanese economies. They conclude that first, news play a relatively more important role in the U.S. than in Japan, second a news shock with longer expectations horizon has a greater impact on nominal variables and third that the overall effect of TFP on hours worked becomes vague under technological news. Schmitt-Grohé and Uribe (2012) perform a structural Bayesian estimation of the contribution of anticipated shocks to business cycles in the postwar United States. They find that anticipated shocks account for more than two thirds of predicted aggregate fluctuations. Khan and Tsoukalas (2012) add to the relative literature about news, by allowing for both unanticipated and news shocks. By using quarterly data from 1954 to 2004 for the US economy, and by implementing Bayesian methods, they find that unanticipated shocks dominate news shocks in accounting for the unconditional variance of key macroeconomic variables like output, consumption, investment growth and interest rate. Finally Milani and Treadwell (2012) further extend the related literature by examining how news about future policies and unanticipated policy shocks influence the business cycle. They conclude that news have a large, delayed and persistent effect on output, whereas unanticipated shocks have a smaller and short-lived impact.

Angeletos and Lian (2016) and Angeletos and Huo (2018) introduce even more behavioral elements to DSGE models, by assuming myopia towards the future (allowing also for anchoring to the past in the latter case), in an effort to capture deviations of higher-order beliefs from first-order beliefs. They argue that the friction implicit in survey evidence of expectations is large enough to generate sluggishness in the dynamics of inflation and aggregate spending as that standard DSGE models capture by adding ad hoc modeling devices, a result close to Milani (2007). However, we prefer to depart moderately from rational expectations and focus on adaptive learning, following in general the work of Milani (2007) for the case of the Euroarea, as it could be used to provide further behavioral insights, without having to assume ad-hoc expectations rules or exogenous sources of behavioral fluctuations.

As regards the model utilized, we implement a standard dynamic DSGE which incorporates elements both from the real business cycles (capital accumulation and technological shock) and the new-keynesian literature (imperfect competition, sticky prices, sticky wages, Taylor rule for the monetary policy), close to the pioneering works of Smets and Wouters (2003),Christiano et al. (2005) and Erceg et al. (2000). Furthermore, the model consists of two open-economy heterogeneous areas, the Core and the Periphery, who form a currency union, based on the work of Philippopoulos et al. (2017). The model is solved jointly for the two Areas, meaning that events of one Area affect the other.

3 Model

This section analytically describes the model implemented for the scope of our analysis. The baseline model features imperfect competition and Calvo-type nominal rigidities in prices and wages. Furthermore, agents are assumed to have consumption habits. The subsections that follows, analytically describe the problem of each agent and the first order conditions.

3.1 Households

In this section we analytically present the household's consumption bundle, the utility maximization problem with the corresponding first order conditions, as also the wage setting problem.

3.1.1 Consumption Bundle

We follow Philippopoulos et al. (2017) in forming a two-country model, within a common currency union. In particular, the two heterogeneous Euro-areas form a closed economy. Within this set, consumption is further divided into consumption of domestic goods and imported goods. By using a Dixit-Stiglitz aggregator, the composition of each type of consumption good is as follows:

$$C_{j,t}^{H} = \left[\sum_{h=1}^{N} \kappa [C_{j,t}^{H}(h)]^{1/\varepsilon_c} \right]^{\varepsilon_c} \tag{1}$$

$$C_{j,t}^{F} = \left[\sum_{f=1}^{N} \kappa [C_{j,t}^{F}(f)]^{1/\varepsilon_c} \right]^{\varepsilon_c} \tag{2}$$

where $C_{j,t}^{H}, C_{j,t}^{F}$ denote domestic and imported consumption goods respectively, ε_c is the elasticity of substitution across goods and $\kappa = 1/N$ is a weight chosen to avoid scale effects in equilibrium. Having defined $C_{j,t}^{H}$ and $C_{j,t}^{F}$ household j's consumption bundle $C_{j,t}$ is given by:

$$C_{j,t} = \frac{(C_{j,t}^{H})^{\omega}(C_{j,t}^{F})^{1-\omega}}{\omega^{\omega}(1-\omega)^{1-\omega}} \tag{3}$$

where ω is the degree of preference for domestic goods.

3.1.2 Consumption Expenditure, Prices and Terms of Trade

Household's total expenditure will be:

$$P_t C_{j,t} = P_t^H C_{j,t}^H + P_t^F C_{j,t}^F \tag{4}$$

where P_t is the aggregate price level, P_t^H is the price of home tradables and P_t^F is the price of foreign, imported trabables, expressed in the domestic currency.

Each household's total consumption expenditure on home goods and foreign goods are respectively:

$$P_t^H C_{j,t}^H = \sum_{h=1}^{N} \kappa P_t^H(h) C_{j,t}^H(h) \tag{5}$$

$$P_t^F C_{j,t}^F = \sum_{f=1}^{N} \kappa P_t^F(f) C_{j,t}^F(f) \tag{6}$$

where $P_t^H(h)$ is the price of variety h produced at home and $P_t^F(f)$ is the price of variety f produced abroad, denominated in the domestic currency.

By assuming that the law of one price holds, P_t^F will be:

$$P_t^F(f) = Z_t P_t^{H\star}(f) \tag{7}$$

where Z_t is the nominal exchange rate and $P_t^{H\star}(f)$ is the price of variety f produced abroad denominated in foreign currency. Hence, the terms of trade (t.o.t) will be defined as:

$$t.o.t. \equiv \frac{P_t^F}{P_t^H} = \frac{Z_t P_t^{H\star}}{P_t^H} \tag{8}$$

3.1.3 Household's Problem

The economy is populated by a large number of identical, infinitely lived consumers in a cashless economy, who maximize in each period their utility function which has the following separable form:

$$U_t = u(C_{j,t}, C_{j,t-1}) - \upsilon(L_{j,t}(i)) \tag{9}$$

where $C_{q,j}$ is agent's j's consumption at time q ($q = t, t-1$) and $L_{j,t}$ are labor hours. The function u is increasing and concave in C while the function υ is increasing and convex in L. We assume the following, constant elasticity of substitution (CES) utility functions for u and υ respectively:

$$u(C_{j,t}, C_{j,t-1}) = \frac{(C_{j,t} - \eta C_{j,t-1})^{1-\sigma}}{1-\sigma} \tag{10}$$

$$\upsilon(L_{j,t}) = \Phi \frac{L_{j,t}^{1+\phi}}{1+\phi} \tag{11}$$

where σ is the relative risk aversion coefficient, $0 \leq \eta \leq 1$ measures the degree of habit formation, $\Phi > 0$ is the relative preference for leisure and finally ϕ is the marginal disutility in respect of labor supply. Household's budget constraint in nominal terms is:

$$P_t C_{j,t} + \frac{B_{j,t+1}}{R_t^B} + P_t I_{j,t} = B_{j,t} + W_{j,t} L_{j,t} + R_t^k K_{j,t} + \mathit{\Pi}_t \tag{12}$$

where P_t is the aggregate price level, R_t^B is the bond's rate of return which is equal to the basic interest rate determined by the Central Bank and Π_t are the monopoly profits from wholesaler's operations. Since agents are identical, a symmetric equilibrium implies that $C_{j,t} = C_t$, $B_{j,t} = B_t$ and $I_{j,t} = I_t$ hence the term j can be dropped. As explained in the next section, households supply differentiated labor services and thus the term j can't be dropped.

Using the law of motion for capital:

$$K_{t+1} = (1-\delta) K_t + I_t \tag{13}$$

where δ is the depreciation rate of capital, the budget constraint of the representative household is simplified to:

$$P_t C_t + \frac{B_{t+1}}{R_t^B} + P_t (K_{t+1} - (1-\delta) K_t) = B_t + W_{j,t} L_{j,t} + R_t^k K_t + \mathit{\Pi}_t \tag{14}$$

By using (4), the real budget constraint can be written as a function of domestic and foreign consumption:

$$\frac{P_t^H}{P_t} C_{j,t}^H + \frac{P_t^F}{P_t} C_{j,t}^F + \frac{B_{t+1}}{P_t R_t^B} + (K_{t+1} - (1-\delta) K_t) = \frac{B_t}{P_t} + \frac{W_{j,t}}{P_t} L_{j,t} + \frac{R_t^k}{P_t} K_t + \frac{\mathit{\Pi}_t}{P_t} \tag{15}$$

The representative household's problem is to maximize her present value of lifetime utility, discounted by β, by optimally chosen their current consumption (C_t), end of period capital (K_{t+1}) and amount of government bonds (B_{t+1}). Given the wage $W_{j,t}$, agents supply as many hours on labor market j, $L_{j,t}$ as demanded by firms according to their optimality condition. Thus, the Lagrange function of household's problem is:

$$\mathscr{L}_t = \beta^t \Bigg[(u(C_t, C_{t-1}) - \upsilon(L_{j,t})) + \lambda_t \Bigg(\frac{B_t}{P_t} + \frac{W_{j,t}}{P_t} L_{j,t} + \frac{R_t^k}{P_t} K_t + \frac{\Pi_t}{P_t} - \\ - \Bigg(C_t + \frac{B_{t+1}}{P_t R_t^B} + (K_{t+1} - (1-\delta) K_t) \Bigg) \Bigg) \Bigg] \tag{16}$$

Then, the first order conditions (FOCs) for the representative household's utility maximization problem, subject to her budget constraint (eq. 15) are the following:

- With respect to (from now on wrt) C_t^H:

$$\frac{P_t^H}{P_t} \lambda_t = \frac{\theta u_t}{\theta C_t} \frac{\theta C_t}{\theta C_t^H} + \beta \frac{\theta u_{t+1}}{\theta C_t} \frac{\theta C_t}{\theta C_t^H} \tag{17}$$

- wrt C_t^F:

$$\frac{P_t^F}{P_t} \lambda_t = \frac{\theta u_t}{\theta C_t} \frac{\theta C_t}{\theta C_t^F} + \beta \frac{\theta u_{t+1}}{\theta C_t} \frac{\theta C_t}{\theta C_t^F} \tag{18}$$

- wrt B_{t+1}:

$$\frac{\lambda_t}{\lambda_{t+1}} = \beta R_t^B \tag{19}$$

  Eq. 19 is the Euler equation I.

- wrt K_{t+1}:

$$-\beta^t \lambda_t + \beta^{t+1} \lambda_{t+1} \left[(1-\delta) + \frac{R_{t+1}^k}{P_{t+1}} \right] = 0 \\ \Rightarrow \frac{\lambda_t}{\lambda_{t+1}} = \beta \left(1 - \delta + \frac{R_{t+1}^k}{P_{t+1}} \right) \tag{20}$$

  Eq. 20 is the Euler Equation II.

3.1.4 Wage setting

Following Erceg et al. (2000) we assume that a continuum of households, indexed on the unit interval, supply differentiated labor services within a market structure of monopolistic competition. This service is sold to a representative firm (employment agency), whose task is to aggregate these different types of labor (L_j) into a single labor input (L). As in Erceg et al., we assume that the representative labor aggregator combines households' labor hours in the same proportion as firms would choose, i.e. household's labor supply equals the sum of firm's demands. The technology utilized by the employment agency, as commonly set in the related literature, has the following Dixit-Stiglitz form:

$$L_t = \left(\int_0^1 L_{j,t}^{1/\varepsilon_w} dj \right)^{\varepsilon_w} \tag{21}$$

where $1 \leq \varepsilon_w \leq \infty$ is the elasticity of substitution between differentiated jobs.[1] Each type of labor j is paid a wage $W_{j,t}$. The problem of the labor union is to maximize its union member's utility, subject to household's budget constraint (14) and the labor aggregation technology (21). The demand curve for $L_{j,t}$ is given by:

$$L_{j,t} = L_t \left(\frac{W_t}{W_{j,t}} \right)^{\varepsilon_w/(\varepsilon_w - 1)} \tag{22}$$

where W_t is the aggregate wage rate, i.e. the price of L_t, which both are taken by the households as given. It is straight forward to show that W_t is related to $W_{j,t}$ via:

$$W_t = \left(\int_0^1 W_{j,t}^{1/(1-\varepsilon_w)} dj \right)^{1-\varepsilon_w} \tag{23}$$

In each period a household has a constant probability $1 - \theta_w$ to optimally re-set it's wage. The ability to reoptimize is independent across households and time. Following Christiano et al. (2005), if a household cannot reoptimize it's wage at time t, it sets $W_{j,t}$ according to the following, inflation indexation rule:

$$W_{j,t} = \pi_{t-1} W_{j,t-1} \tag{24}$$

When the representative agent is able to set it's optimal wage, by using eq.(22), the foc of (16) wrt $W^\star_{j,t}$ is the following:

$$0 = E_t \sum_{t=0}^{\infty} (\beta\theta_w)^t \left(\frac{\lambda_{j,t}}{\upsilon_{L_{j,t}}} \frac{W^\star_{j,t}}{P_t} - \mu^w \right) \tag{25}$$

where $\mu^w = \frac{\varepsilon_w}{(\varepsilon_w - 1)}$ is the constant, wage mark-up in the case of wage flexibility.

[1] We adopt the notation using in Christiano et al. (2005)

Using (23), (24) and (25) the aggregate wage level will be:

$$W_t = \left(\int_0^1 W_{j,t}^{1/(1-\varepsilon_w)} dj \right)^{1-\varepsilon_w} \tag{26}$$

$$\Rightarrow W_t^{1/(1-\varepsilon_w)} = \int_0^{\theta_w} (\pi_{t-1} W_{t-1})^{1/(1-\varepsilon_w)} dj + \int_{\theta_w}^1 (W_t^*)^{1/(1-\varepsilon_w))} dj$$

$$\Rightarrow W_t^{1/(1-\varepsilon_w)} = \theta_w (\pi_{t-1} W_{t-1})^{1/(1-\varepsilon_w)} + (1-\theta_w)(W_t^*)^{1/(1-\varepsilon_w)}$$

$$\Rightarrow W_t = \left(\theta_w (\pi_{t-1} W_{t-1})^{1/(1-\varepsilon_w)} + (1-\theta_w)(W_t^*)^{1/(1-\varepsilon_w)} \right)^{(1-\varepsilon_w)} \tag{27}$$

3.2 Firms

We adopt the intermediate-final producer as it is commonly used in the New-Keynesian literature: The economy's producing sector is divided into two parts: an intermediate goods sector (wholesalers) and a final goods sector (retailers). Wholesalers possess monopolictic power, producing differentiable goods which are then sold to the Retail firms. Then, Retailers convert the bundle of goods to a unique, aggregate good, within a structure of perfect competition.

3.2.1 Retailers

The representative retailer maximizes it's profit function, subject to the aggregation technology (Dixit and Stiglitz (1977)):

$$\max_{\{Y_{j,t}\}} P_t Y_t - \int_0^1 P_{j,t} Y_{j,t} dj \tag{28}$$

s.t.:

$$Y_t = \left(\int_0^1 Y_{j,t}^{1/\varepsilon_c} dj \right)^{\varepsilon_c} \tag{29}$$

By replacing (29) in (28), the first order condition wrt $Y_{j,t}$, after some manipulation, leads to:

$$Y_{j,t} = Y_t \left(\frac{P_t}{P_{j,t}} \right)^{\varepsilon_c/(\varepsilon_c - 1)} \tag{30}$$

which is the demand function for the wholesale good j. Substituting (30) in (29) gets:

$$P_t = \left[\int_0^1 P_{j,t}^{1/(1-\varepsilon_c)} dj \right]^{1-\varepsilon_c} \tag{31}$$

Due to the fact that the Retailers compete in a regime of perfect competition, allows us to set

$\Pi_t^R = 0$.

3.2.2 Wholesalers

Wholesale firms, which are price setters, solve their problem in two stages. First, they determine the amount of capital and labor given the prices of the producing factors (return on capital R_t^k and wages W_t) in order to minimize their total production cost:

$$\min_{\{K_{j,t},L_{j,t}\}} R_t^k K_{j,t} + W_t L_{j,t} \tag{32}$$

subject to the Cobb-Douglas production function:

$$Y_{j,t} = A_t K_{j,t}^{\alpha} L_{j,t}^{1-\alpha} \tag{33}$$

where A_t is the common technology, which follows an AR(1) process:

$$logA_t = (1-\rho_A)logA_{ss} + \rho_A logA_{t-1} + \varepsilon_t^A \tag{34}$$

where ε_t^A is an i.i.d. technological shock, $\varepsilon_t^A \sim N(0, \sigma_A^2)$ and ρ_A is the autoregressive parameter the technological evolution, with $\rho_A < 1$ to ensure the stationarity of the process. The Lagrangian of the problem is:

$$\mathscr{L}_{j,t} = R_t^k K_{j,t} + W_t L_{j,t} + MC_{j,t}(Y_{j,t} - A_t K_{j,t}^{\alpha} L_{j,t}^{1-\alpha}) \tag{35}$$

where the Lagrange multiplier $MC_{j,t}$ can be interpreted as wholesaler's j marginal cost. The FOCs are:

- wrt L_t:

$$\frac{W_t}{P_{j,t}} = (1-\alpha)\frac{MC_{j,t}}{P_t}\frac{Y_{j,t}}{L_{j,t}} \tag{36}$$

- wrt K_t:

$$\frac{R_t^k}{P_t} = \alpha\frac{MC_{j,t}}{P_t}\frac{Y_{j,t}}{K_{j,t}} \tag{37}$$

Eq. 36 is the demand for labor and eq. 37 is the demand for capital for the wholesale firm j. Dividing these two terms leads to:

$$\frac{W_t}{R_t^k} = \frac{1-\alpha}{\alpha}\frac{K_t}{L_t} \tag{38}$$

Finally, as regards the marginal cost, after some manipulation(for further details, see Appendix A A.2), this is equal to:

$$MC_{j,t} = \frac{1}{A_t}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t^k}{\alpha}\right)^{\alpha}$$

Due to the fact that all wholesale firms face the same problem, the j term can be removed:

$$MC_t = \frac{1}{A_t}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t^k}{\alpha}\right)^{\alpha} \tag{39}$$

which can be also written in real terms:

$$\begin{aligned} mc_t \equiv \frac{MC_t}{P_t} &= \frac{1}{A_t}\left(\frac{W_t/P_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t^k/P_t}{\alpha}\right)^{\alpha} \\ &= \frac{1}{A_t}\left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^k}{\alpha}\right)^{\alpha} \end{aligned} \tag{40}$$

In the second stage of the wholesaler's problem, the firm optimally chooses the price of her good:

$$\max_{\{P_{j,t}^*\}} = E_t\sum_{i=0}^{\infty}(\beta\theta_f)^i(P_{j,t}^*Y_{j,t+1} - TC_{j,t+i}) \tag{41}$$

Using Retailer's optimality condition (eq. 30), wholesaler's problem becomes:

$$\max_{\{P_{j,t}^*\}} = E_t\sum_{i=0}^{\infty}(\beta\theta_f)^i\left[P_{j,t}^*Y_{t+1}\left(\frac{P_{t+i}}{P_{j,t}^*}\right)^{\varepsilon_c/(\varepsilon_c-1)} - Y_{t+i}\left(\frac{P_{t+i}}{P_{j,t}^*}\right)^{\varepsilon_c/(\varepsilon_c-1)}MC_{t+i}\right] \tag{42}$$

The FOC of this problem is:

$$P_{j,t}^* = \mu^f E_t\sum_{i=0}^{\infty}(\beta\theta_f)^i MC_{t+i} \tag{43}$$

where $\mu^f = \frac{\varepsilon_c}{(\varepsilon_c-1)}$ is the constant, price mark-up in the case of wage flexibility, meaning that firm j's optimal reset price is a constant mark-up over the discounted sum of firm j's expected future nominal marginal costs.

Since, as we can notice from the previous equation, which determines the optimal price level of the good Y_j, this expression is independent of the term j, hence all firms have the same markup on the marginal cost. Therefore, in each period, $1-\theta_f$ firms optimally select this price level, whereas the remaining θ_f firms follow an indexation rule, as proposed by Christiano et al. (2005):

$$P_{j,t} = \pi_{t-1} P_{j,t-1} \tag{44}$$

Thus, the aggregate price level, using eq.31 and eq.44:

$$\begin{aligned} P_t &= \left(\int_0^1 P_{j,t}^{1/(1-\varepsilon_c)} dj \right)^{1-\varepsilon_c} \\ \Rightarrow P_t^{1/(1-\varepsilon_c)} &= \int_0^{\theta_f} (\pi_{t-1} P_{t-1})^{1/(1-\varepsilon_c)} dj + \int_{\theta_f}^1 (P_t^*)^{1/(1-\varepsilon_c))} dj \\ \Rightarrow P_t^{1/(1-\varepsilon_c)} &= \theta_f (\pi_{t-1} P_{t-1})^{1/(1-\varepsilon_c)} + (1-\theta_f)(P_t^*)^{1/(1-\varepsilon_c)} \\ \Rightarrow P_t &= \Big(\theta_f (\pi_{t-1} P_{t-1})^{1/(1-\varepsilon_c)} + (1-\theta_f)(P_t^*)^{1/(1-\varepsilon_c)} \Big)^{(1-\varepsilon_c)} \end{aligned} \tag{45}$$

3.3 Monetary and fiscal policy

As regards the monetary policy, we assume that the monetary policy authority responds to deviations of inflation and output from their targets, as is commonly assumed. Following Dellas and Tavlas (2005), monetary policy (MP) is conducted according to a Taylor rule constructed as a weighed average of the rules of Core & Periphery. The rule for each country is:

$$\left(\frac{R_t^{B,A}}{R_{ss}^{B,A}} \right) = \left(\frac{\pi_t^A}{\pi_{ss}^A} \right)^{\varphi_\pi} \left(\frac{Y_t^A}{Y_t^{n,A}} \right)^{\varphi_y} \tag{46}$$

where the term $\frac{Y_t^A}{Y_t^{n,A}}$ denotes the deviation of output from it's natural level.

Then the CB changes the nominal interest rate by weighting the two Taylor Rules for each country, according to their populations. Furthermore, in order to stay close to Milani (2007), we include a lag term of the interest rate, however as the hybrid interest rate rule can be considered as a mechanical source of persistence, we allow this term to not be included in the "No Mechs" case. Hence, the central bank adjusts the main interest rate according to:

$$R_t^{CB} = \rho_{CB} R_{t-1}^{CB} + (1-\rho_{CB})(w^C R_t^{B,C} + w^P R_t^{B,P}) + \varepsilon_t^s \tag{47}$$

where ε_t^S is an i.i.d shock term representing unexpected disturbances in the monetary policy.

As regards the fiscal policy, we assume that governments have access to lump-sum taxes and pursue a Ricardian fiscal policy. As explained in Christiano et al., under this type of policy, the details of tax policy have no impact on inflation and other aggregate economic variables and there is no need of further specification of the fiscal policy.

3.3.1 Equilibrium condition

Equilibrium in the goods market is expressed by the resource constraint:

$$Y_t = C_t + I_t = C_t + K_{t+1} - (1-\delta)K_t \tag{48}$$

3.3.2 Definition of equilibrium

We can define the equilibrium of this model, to be a structure of allocations $\{C_t, C_t^H, C_t^F, B_t, I_t, K_{t+1}, L_t, Y_t, MC_t, \Pi_t, \lambda_t\}$ and of prices $\{P_t, P_t^H, P_t^F, P_t^{H\star}, W_t, W_t^{\star}, R_t^k, R_t^B, \pi_t\}$, given the exogenous variables $\{A_t, S_t\}_{t=0}^{\infty}$ such that:

- Households maximize their welfare function, st their budget constraint (eq. 12) and the law of motion for capital (eq. 13). The first order conditions of this problem (eqs. 17, 18, 19 and 20) are satisfied.
- The Employment Agent sets the optimal wage according to eq. (25) whereas the general wage level is determined according to (27).
- Retailers & Wholesalers maximize their profits and their FOCs are satisfied (eqs 38, 40 and 43.
- Prices evolve according to (45).
- Central Bank follows a simple Taylor Rule responding to deviations of inflation, output gap & wage inflation (eq. 47).
- The equilibrium condition (eq. 48) and the resource constraint (eq. 33) are satisfied.
- The exogenous processes for technology and monetary policy shock follow eqs. 34 and **??** respectively.

Table 3.1 summarizes the structure of the decentralized equilibrium system, which consists of 39 equations in 39 unknowns $\{C_t^C, C_t^P, C_t^{H,C}, C_t^{H,P}, C_t^{F,C}, C_t^{F,P}, B_t^C, B_t^P, I_t^C, I_t^P, K_t^C, K_t^P, L_t^C, L_t^P, Y_t^C, Y_t^P, MC_t^C, MC_t^P, \lambda_t^C, \lambda_t^P, P_t^C, P_t^P, P_t^{H,C}, P_t^{H,P}, P_t^{F,C}, P_t^{F,P}, P_t^{\star,C}, P_t^{\star,P}, W_t^C, W_t^P, W_t^{\star,C}, W_t^{\star,P}$ $, R_t^{k,C}, R_t^{k,P}, R_t^{B,C}, R_t^{B,P}, R_t^{CB}, \pi_t^{w,C}, \pi_t^{w,P}\}$. This is given the values of feedback policy coefficients as defined in subsection (3.3), the path of exogenous shock processes $\left\{\varepsilon_t^{a,A}, \varepsilon_t^s\right\}_{t=0}^{\infty}$ and initial conditions for the state variables.

To solve this system, we take a first-order approximation around its steady state, so as to be able to implement the learning approach as in Evans and Honkapohja (2001). Section 3.4 describes the log-linearized procedure, whereas table A.1 summarizes the structure of the reduced form log-linearized model.[2]

Table 3.1: Structure of Model

Equation	Definition
$K^A_{t+1} = (1-\delta)K^A_t + I^A_t$	Law of Motion for Capital
$C^A_t = \frac{(C^{H,A}_t)^{\omega_A}(C^{F,A}_t)^{1-\omega_A}}{\omega_A^{\omega_A}(1-\omega_A)^{1-\omega_A}}$	Household's Consumption Bundle
$P^A_t C^A_t = P^{H,A}_t C^{H,A}_t + P^{F,A}_t C^{F,A}_t$	Total Consumption Expenditure
$P^{F,C}_t = P^{H,P}_t$	Law of one Price for Core
$P^{F,P}_t = P^{H,C}_t$	Law of one Price for Periphery
$\frac{P^{H,A}_t}{P^A_t}\lambda^A_t = \frac{\theta u^A_t}{\theta C^A_t}\frac{\theta C^A_t}{\theta C^{H,A}_t} + \beta_A \frac{\theta u^A_{t+1}}{\theta C_t}\frac{\theta C^A_t}{\theta C^{H,A}_t}$	FOC wrt $C^{H,A}_t$
$\frac{P^{F,A}_t}{P^A_t}\lambda^A_t = \frac{\theta u^A_t}{\theta C^A_t}\frac{\theta C^A_t}{\theta C^{F,A}_t} + \beta_A \frac{\theta u^A_{t+1}}{\theta C^A_t}\frac{\theta C^A_t}{\theta C^{F,A}_t}$	FOC wrt $C^{F,A}_t$
$\frac{\lambda^A_t}{\lambda^A_{t+1}} = \beta_A(1+R^{B,A}_t)$	Euler I
$\frac{\lambda^A_t}{\lambda^A_{t+1}} = \beta_A\left(1-\delta_A + \frac{R^{k,A}_{t+1}}{P^A_{t+1}}\right)$	Euler II
$\frac{W^{*,A}_{j,t}}{P^A_t} = \left(\frac{\varepsilon_w}{\varepsilon_w - 1}\right) E_t \sum_{i=0}^{\infty}(\beta_A\theta_w)^i \left(\frac{\Phi_A L^{\phi,A}_{t+i,j}}{\lambda^A_{t+i}}\right)$	Optimal Wage
$W^A_t = \left(\theta_w(\pi^A_{t-1}W^A_{t-1})^{1/(1-\varepsilon_w)} + (1-\theta_w)(W^{*,A}_t)^{1/(1-\varepsilon_w)}\right)^{(1-\varepsilon_w)}$	Level of Aggregate Wage
$\pi^{w,A}_t = W^A_t / W^A_{t-1}$	Gross wage Inflation Rate
$\frac{R^{k,A}_t}{P^A_t} = \alpha_A \frac{MC^A_t}{P^A_t}\frac{Y^A_t}{K^A_t}$	Demand for Capital
$\frac{W^A_t}{P^A_t} = (1-\alpha_A)\frac{MC^A_t}{P^A_t}\frac{Y^A_t}{L^A_t}$	Demand for Labor
$P^{*,A}_t = \frac{\varepsilon_c}{(\varepsilon_c - 1)} E_t \sum_{i=0}^{\infty}(\beta_A\theta)^i MC^A_{t+i}$	Optimal Price Level
$P^A_t = \left(\theta_{f,A}(\pi^A_{t-1}P^A_{t-1})^{1/(1-\varepsilon_{c,A})} + (1-\theta_{f,A})(P^{*,A}_t)^{1/(1-\varepsilon_{c,A})}\right)^{(1-\varepsilon_{c,A})}$	General Price Level
$\frac{MC^A_t}{P^A_t} = \frac{1}{A^A_t}\left(\frac{W^A_t/P^A_t}{1-\alpha_A}\right)^{1-\alpha A}\left(\frac{R^{k,A}_t/P^A_t}{\alpha_A}\right)^{\alpha A}$	Marginal Cost of Wholesaler's firm
$\left(\frac{R^{B,A}_t}{R^{B,A}_{ss}}\right) = \left(\frac{\pi^A_t}{\pi^A_{ss}}\right)^{\varphi_\pi}\left(\frac{Y^A_t}{Y^{n,A}}\right)^{\varphi_y}$	Taylor Rule of Each Area
$R^{CB}_t = \rho_{CB}R^{CB}_{t-1} + (1-\rho_{CB})(w^C R^{B,C}_t + w^P R^{B,P}_t) + \varepsilon^s_t$	Taylor Rule of Central Bank
$Y^A_t = C^A_t + I^A_t$	Equilibrium Condition
$Y^A_t = A^A_t K^{\alpha_A,A}_t L^{1-\alpha_A,A}_t$	Resource Constraint
$logA^A_t = (1-\rho_{a,A})logA^A_{ss} + \rho_{a,A}logA^A_{t-1} + \varepsilon^{a,A}_t$	Evolution of Technology

Notes:
1. A denotes Area, either Core or Periphery
2. C,P denotes Core and Periphery respectively

[2]The steady state version of the model can be found in the Appendix A.3.

3.4 Log-linearized model

Now, we can proceed to the log-linearization of the model, around the steady state. First, log-linearize the optimal price level (eq.43):

$$P_{ss}\hat{P}_t^* = \frac{\varepsilon_c}{(\varepsilon_c - 1)} MC_{ss} E_t \sum_{i=0}^{\infty} (\beta\theta)^i M\hat{C}_{t+1} \tag{49}$$

The marginal cost, at the steady state, is $MC_{ss} = \frac{\varepsilon_c}{(\varepsilon_c-1)} \frac{1}{(1-\beta\theta)} P_{ss}$, hence, the log-linearized optimal price level can be written:

$$\hat{P}_t^* = (1-\beta\theta) E_t \sum_{i=0}^{\infty} (\beta\theta)^i M\hat{C}_{t+1} \tag{50}$$

Second, following Gali (2015) and Celso José (2016) the general price level (eq.45) is log-linearized and appropriately manipulated in order to derive the New Keynesian Phillips Curve as follows:

$$\frac{1}{(1-\varepsilon_c)} P_{ss}^{1/(1-\varepsilon_c)} \hat{P}_t = \frac{1}{(1-\varepsilon_c)} \theta_f (\pi_{ss}^f P_{ss})^{1/(1-\varepsilon_c)} (\hat{\pi_{t-1}}^f + \hat{P_{t-1}}) + (1/(1-\varepsilon_c))(1-\theta_f) P_{ss}^{1/(1-\varepsilon_c)} \hat{P}_t^*$$

$$\Rightarrow \hat{P}_t = \theta_f \hat{\pi_{t-1}}^f + \theta_f \hat{P_{t-1}} + (1-\theta_f)(1-\beta\theta_f) E_t \sum_{i=0}^{\infty} (\beta\theta_f)^i M\hat{C}_{t+1} \tag{51}$$

$$\Rightarrow \cdot(1-\beta\theta_f L^{-1}) \Rightarrow \theta_f(\hat{P}_t - \hat{P_{t-1}}) = \beta\theta_f(E_t \hat{P_{t+1}} - \hat{P}_t) + (1-\theta_f)(1-\beta\theta_f)(\hat{MC_t} - \hat{P}_t))$$

$$\Rightarrow \hat{\pi_t}^f = \beta E_t \hat{\pi_{t+1}}^f + \kappa_f(\hat{mc_t}) \tag{52}$$

where $\kappa_f \equiv \left(\frac{(1-\theta_f)(1-\beta\theta_f)}{\theta_f}\right)$ and $\hat{mc_t}$ is the log-linearized, real marginal cost, which can be derived from eq. RF.6:[3]

$$\hat{mc_t} = \hat{w}_t + \left(\frac{\alpha}{1-\alpha}\right)\hat{y}_t + \left(\frac{-1}{1-\alpha}\right)\hat{a}_t + \left(\frac{-\alpha}{1-\alpha}\right)\hat{k}_t \tag{53}$$

meaning that the real marginal cost is the real cost of labor ($\hat{w}_t$) minus the marginal product of labor. Following an analogous procedure, using (27) and (25), the log-linearized New-Keynesian Phillips curve for wages equation will be:

$$\hat{\pi_t}^w = \beta E_t \hat{\pi_{t+1}}^w + \kappa_w(\phi\hat{l_t} - \hat{\lambda}_t - \hat{w}_t) \tag{54}$$

where $\hat{\pi_t^w} = \hat{w}_t - \hat{w_{t-1}}$ and $\kappa_w \equiv \left(\frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w}\right)$

The log-linearized, model is summarized in table 3.2. By further manipulating the final system of equations of the model, all variables can be written as a function of $\{y_t^A, w_t^A, c_t^A, \pi_t^A, k_t^A, r_t^{CB}, a_t^A\}$.

[3] Further details are available in the Appendix (A.4).

Further details about the derivation of the reduced form of the log-linearized model can be found on A.4 and summarized on table A.1.

Table 3.2: Structure of the Log-Linerarized Model

Equation	**Definition**
$\lambda_t^A - \lambda_{t+1}^A = r_t^{B,A}$	Euler I
$\lambda_t^A - \lambda_{t+1}^A = \beta R_{ss}^{K,A}(E_t r_{t+1}^{K,A})$	Euler II
$\pi_t^A - \gamma\pi_{t-1}^A = \beta(E_t\pi_{t+1}^A - \gamma\pi_t^A) + \kappa_A(mc_t^A)$	NK Phillips Curve
$\pi_t^{W,A} = \beta(E_t\pi_{t+1}^{W,A}) + \kappa_A^w(\phi_A l_t^A - \lambda_t^A - w_t^A + p_t^A)$	Phillips equation for Wages
$y_t^A = \frac{c_{ss}^A}{y_{ss}^A}c_t^A + \frac{k_{ss}^A}{y_{ss}^A}k_{t+1}^A - (1-\delta_A)\frac{k_{ss}^A}{y_{ss}^A}k_t^A$	Equilibrium Condition
$r_t^{K,A} - w_t^A = l_t^A - k_t^A$	Demand for K_t/L_t
$mc_t^A = -a_t^A + (1-\alpha^A)w_t^A + \alpha^A r_t^{K,A}$	MC of Wholesaler
$y_t^A = a_t^A + \alpha^A k_t^A + (1-\alpha^A)l_t^A$	Production Function
$\pi_t^A = p_t^A - p_{t-1}^A$	Price Inflation
$\pi_t^{W,A} = w_t^A - w_{t-1}^A$	Wage Inflation
$r_t^{B,A} = \rho_{CB} r_{t-1}^{CB} + (1-\rho_{CB})\left[\phi_\pi \pi_t^A + \phi_Y(y_t^A) + \phi_W(\pi_t^{W,A})\right] + \varepsilon_t^s$	Evolution of EuroArea's (C & P) r^G
$r_t^{CB} = w_C r_t^{B,C} + w_P r_t^{B,P}$	CB's Interest Rate
$c_t^A = \omega_A c_t^{H,A} + (1-\omega_A)c_t^{F,A}$	Household's Consumption Bundle
$(p_{ss}^A c_{ss}^A)(p_t^A + c_t^A) = (p_{ss}^{H,A} c_{ss}^{H,A})(p_t^{H,A} + c_t^{H,A}) + (p_{ss}^{F,A} c_{ss}^{F,A})(p_t^{F,A} + c_t^{F,A})$	Total Consumption Expenditure
$\frac{p_{ss}^{H,A}\lambda_{ss}^A}{P_{ss}^A}\left(p_t^{H,A} + \lambda_t^A - p_t^A\right) = q_{H,A}[(1+\beta\eta_A^2)c_t^A + (-\eta_A)c_{t-1}^A + (-\eta_A\beta)E_t c_{t+1}^A] + \ldots$ $+z_{H,A}\left[(\omega_A - 1)c_t^{H,A} + (1-\omega_A)c_t^{F,A}\right]$	FOC wrt C_t^H
$\frac{p_{ss}^{F,A}\lambda_{ss}^A}{P_{ss}^A}\left(p_t^{F,A} + \lambda_t^A - p_t^A\right) = q_{F,A}[(1+\beta\eta_A^2)c_t^A + (-\eta_A)c_{t-1}^A + (-\eta_A\beta)E_t c_{t+1}^A] + \ldots$ $+z_{F,A}\left[\omega_A c_t^{H,A} + (-\omega_A)c_t^{F,A}\right]$	FOC wrt C_t^F
$p_t^{F,C} = p_t^{H,P}$	Law of One Price for Core
$p_t^{F,P} = p_t^{H,C}$	Law of One Price for Periphery
$a_t^A = \rho_{a,A} a_{t-1}^A + \varepsilon_t^{a,A}$	Evolution of Technology

Notes:

1. $q_{H,A} = \left[\left(\frac{\omega_A (c_{ss}^{H,A})^{(\omega_A-1)}(c_{ss}^{F,A})^{(1-\omega_A)}}{\omega_A^{\omega_A}(1-\omega_A)^{(1-\omega_A)}}\right)((-\sigma_A c_{ss}^A)((c_{ss}^A(1-\eta_A))^{(-(\sigma_A+1))})\right]$
2. $z_{H,A} = c_{ss}^A(c_{ss}^A(1-\eta_A))^{(-\sigma_A-1)}\left[\left(\frac{(1-\eta_A\beta)}{\omega_A^{\omega_A}(1-\omega_A)^{(1-\omega_A)}}\right)\left(\omega_A(c_{ss}^{H,A})^{(\omega_A-1)}(c_{ss}^{F,A})^{(1-\omega_A)}\right)\right]$
3. $q_{F,A} = \left[\left(\frac{(1-\omega_A)(c_{ss}^{H,A})^{\omega_A}(c_{ss}^{F,A})^{(-\omega_A)}}{\omega_A^{\omega_A}(1-\omega_A)^{(1-\omega_A)}}\right)((-\sigma_A c_{ss}^A)((c_{ss}^A(1-\eta_A))^{(-(\sigma_A+1))})\right]$
4. $z_{F,A} = c_{ss}^A(c_{ss}^A(1-\eta_A))^{(-\sigma_A-1)}\left[\left(\frac{(1-\eta_A\beta)}{\omega_A^{\omega_A}(1-\omega_A)^{(1-\omega_A)}}\right)\left((1-\omega_A)(c_{ss}^{H,A})^{\omega_A}(c_{ss}^{F,A})^{(-\omega_A)}\right)\right]$

3.5 Learning

According to the learning literature, agents do not know the Rational Expectation Equilibrium (REE) and try to estimate it using econometric techniques. We distinguishe betweeen two cases:

1. Under the presence of mechanical sources of persistence agents are assumed to know the correct structure of the unique RE solution (from now on this model will be referred as "All Mechs").

2. Without the presence of such mechanisms, agents are allowed to assume that the evolution of the control variables, depends also on variables beyond the fundamentals (from now on this model will be referred as "No Mechs").

Agents formulate their expectations $\tilde{x_t}$ according to the perceived law of motion (PLM):

$$\tilde{x_t} \equiv \begin{pmatrix} E_{t-1}y_t \\ E_{t-1}\pi_t \\ E_{t-1}c_t \\ E_{t-1}w_t \\ E_{t-1}r_t^{CB} \end{pmatrix} = \phi_{1,t} \begin{pmatrix} y_{t-1} \\ \pi_{t-1} \\ c_{t-1} \\ w_{t-1} \\ r_{t-1}^{CB} \end{pmatrix} + \phi_{2,t} \begin{pmatrix} k_t \\ a_t \\ \varepsilon_t^s \\ 0 \\ 0 \end{pmatrix} \tag{55}$$

In case 1, all variables are considered States whereas in case 2, only $\{k_t, a_t\}$ are states and if any of $\phi_{1,t} \neq 0 \Rightarrow$ provides evidence of endogenously created persistence. The rational expectations solutions (RES) nests as a special case in both cases. By replacing the expectation terms in the original equations, using PLM, we get the actual law of motion (ALM) T as a function of agent's estimates ϕ_t:

$$\tilde{x_t} \equiv \begin{pmatrix} E_{t-1}y_t \\ E_{t-1}\pi_t \\ E_{t-1}c_t \\ E_{t-1}w_t \\ E_{t-1}r_t^{CB} \end{pmatrix} = T_1(\phi_t) \begin{pmatrix} y_{t-1} \\ \pi_{t-1} \\ c_{t-1} \\ w_{t-1} \\ r_{t-1}^{CB} \end{pmatrix} + T_2(\phi_t) \begin{pmatrix} k_{t-1} \\ a_{t-1} \\ \varepsilon_t^s \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{56}$$

where $\phi_t = \{\phi_{1,t}, \phi_{2,t}\}$. Following Evans and Honkapohja (2001) and Milani (2007) we use the constant-gain Least squares (CLS), according to which agent's estimates ϕ_t update according to:

$$\varphi_{t+1} = \varphi_t + \bar{g} R_t^{-1} z_t \left(x_t - \tilde{x_t}\right) \tag{57}$$

$$R_t = R_{t-1} + \bar{g}\left(z_t z_t' - R_{t-1}\right) \tag{58}$$

where z_t is a diagonal matrix containing the endogenous lagged and state variables. Expecting eq. (57) reveals that agents update their estimates ϕ_{t+1} by taking into consideration the difference between the realization x_t and their expectation $\tilde{x_t}$. According to Milani (2007) the constant gain term (0 <

$\bar{g} < 1$) can be interpreted as the speed at which agents learn the RES and needs to be calibrated or estimated. We estimate $\bar{g}$ using Bayesian approach for Core and Periphery separately and we report the corresponding values in table 4.3.

4 Data, calibration and estimation strategy

4.1 Data

Following De Grauwe and Yuemei (2018), in the Core the following countries are included: Austria, Belgium, Finland, France, Germany and Netherlands. On the other hand, Greece, Ireland, Italy, Spain and Portugal constitute the Periphery of the Eurozone.[4]

All data have been extracted from the following databases:

(a) OECD Quarterly National Accounts

(b) OECD Quarterly National Accounts

(c) Eurostat

(d) Oxford Economics

(e) AMECO

Further details on the sources of the data are provided in table 4.1. Real GDP is defined as the gdp chained link, in 2015 million. Real wage is defined as the deflated compensation of employees per quarterly hour worked. Following Gogos et al. (2014) we allocate government consumption and net exports to consumption. Since the implied national income identity, for each area, is $Y_t^A = C_t^A + I_t^A$, given data for real output and investment, the consumption is obtained residually. Inflation is the annualized change of the harmonized CPI and as wage we use the compensation of employees. [5]

Output, capital and labor of each Area are the total sum of the respective variables of each Area's country members, whereas the wage, government bond rates and inflation are the mean value of the Area's country members, weighted by their population share in the Area. Figure A.1 depicts the data for key variables of the model for the period examined (2000Q1-2019Q4), for Core and Periphery, as calculated using the available data. To fit the model with the data, the series are logged and detrended, since we aim to study the business cycles in the two areas of the Eurozone. [6]

[4] We have also examined whether by excluding Ireland from Periphery the main conclusions derived are affected. The detrended output is slightly affected for the period after the global economic crisis, however our conclusions considering the perfomance of the models examined are not affected.

[5] As an alternative, we have also used the inflation implied from the GDP deflator, without the main concludions derived to be altered.

[6] For detrending the data, we use the HP filter with smoothing constant $\lambda = 6400$ as in Canova and Ferroni (2011). Furthermore, we have tested our results for robustness, using other filters, in particular a simple detrending filter and Hamilton (Hamilton (2018)), without affecting the main conclusions driven.

Table 4.1: Sources of data for Core and Periphery

Variable	Unit	Time period	Source
Gross domestic product	Millions of Euros	1960Q1-2019Q4	(a)
Real Gross domestic product	Chain linked volumes (2015), million of euros	1960Q1-2019Q4	(a)
Gross Fixed Capital Formation	Chain linked volumes (2015), million of euros	1960Q1-2019Q4	(c)
Total employment	Thousands of persons	1980Q1-2019Q4	(a)
Compensation of employees	Millions of euros	1980Q1-2019Q4	(a)
Hours worked per employee	Hours	1980Q1-2019Q4	(a)
CPI Inflation rate	Percentage	1980Q1-2019Q4	(d)
Bond rates	Three-month rates	1980Q1-2019Q4	(c)
Working population	Thousands of persons	1980Q1-2019Q4	(d)

Notes:
1. All data that start from 1960Q1 have been constructed using OECD AR series (b), starting from 1980Q1 using the original data, backward projected.
2. Data for compensation of Employees for Greece & Ireland are available from 1995Q1 & 1990Q1 respectively.

4.1.1 Real capital stock

In order to obtain a time series for the quarterly real capital stock, K_t, we follow a procedure similar to Conesa et al. (2007). Using data on real investment I_t the capital series can be derived from the law of motion for capital (eq.(13)). The value for the depreciation rate δ is chosen to be consistent with the annual capital stock to gdp ratio from the AMECO database, for the period of interest (2000Q1-2019Q4). This value is 0.072 and 0.063 for Core and Periphery respectively, which are quarterized.

As regards the initial capital stock value, this is chosen so that the capital–output ratio in the initial period to be equal to the average capital–output ratio over some reference period, in our case 1961–1970. That is:

$$\frac{K_{1960}^A}{Y_{1960}^A} = \frac{1}{10} \sum_{t=1961}^{1970} \frac{K_t^A}{Y_t^A} \tag{59}$$

By choosing 1960 as our initial period, and given that our analysis will focus on the 2000–2019 period, we minimize the effects of the choice of the initial capital value K_0^A on the constructed series of real capital stock. Eqs. (13) for the period $1960Q2 - 2019Q4$ and eq. (59) constitute a system of 261 equations in 261 unknowns which will give us the real capital stock series.

4.1.2 Technology

As regards the technology (TFP) series A_t^A for each Area A, by using the Cobb-Douglas production function (as described in eq. (33)), given data on real capital stock K_t^A, output Y_t^A, hours of work L_t^A and a value for the capital share parameter, α_A (as presented in table 4.2) we compute the series for

TFP as follows:

$$A_t^A = \frac{Y_t^A}{K_t^{\alpha_A, A} L_t^{1-\alpha_A, A}} \tag{60}$$

Having obtained the series for the TFP we assume that it follows an AR(1) process. By regressing the series, we obtain values for the persistence and st. deviation of each series (as described in table ??).

4.1.3 Exogenous monetary policy shock

As regards the exogenous monetary policy shock, in order to avoid any possible correlation with the technological process, we identify it using a simple vector-autoregression (VAR) model, with 4 lags, using data on technology, the residual of the Taylor rule, ECB's main interest rate, output and inflation. Since we estimate the Taylor rule coefficients, we obtain the monetary policy shock jointly with the parameters of the model, using Bayesian estimation. We discuss different procedures of identifying the monetary policy shock in section 6.

4.2 Calibration and econometric methodology

Following Christiano et al. (2005) we partition the model parameters into three groups. The first group is composed of $\{\beta, \sigma, \phi, \delta, \alpha, w^A\}$ which are calibrated. In particular, the weights w^A for each Area are calculated according to the population shares of Core and Periphery (0.59 and 0.41 respectively). The discount factor β is set to 0.9936 and 0.9906, to match an annual interest rate of 2.87% and 4.16% for Core and Periphery respectively.[7] All the parameters calibrated are reported in table (4.2).

The second group consists of the parameters of the exogenous processes which are identified, $\{\rho_A, \sigma_A^A, \sigma_{MP}\}$ also described in table 4.2. Finally the third group concerns the parameters estimated using Bayesian techniques, which includes the various stickiness parameters and the Taylor rule coefficients $\{\theta^{f,A}, \theta^{w,A}, \phi_\pi, \phi_Y, \eta^A, \gamma^A, \rho_{CB}, \bar{g}^A\}$ which are reported in table 4.3.

4.2.1 Bayesian estimation

The model is estimated using full-information Bayesian techniques. Draws are generated using the Metropolis-Hastings algorithm. We run 500000 draws, in order to guarantee the exploration of the parametric space for all parameters estimated discarding the initial 40% as burn-in, as in Milani (2017). The priors are selected closely in line with Milani. Since the stickiness parameters are naturally restricted in the range $[0, 1]$, we let them follow a Beta distribution, except for the price indexation index which we allow the prior to be rather uninformative (Uniform), allowing to freely range within

[7] These interest rate values are the mean values for the Core and Periphery bond rates for the period examined, using data from the EMU convergence criterion series.

Table 4.2: Parameter values for groups 1 and 2

A. Parameters set from Data		**Core**	**Periphery**	**Rationale**
w	Weight for each Area in the taylor rule	0.59	0.41	Mean population share
B. Parameters calibrated from Steady State		**Core**	**Periphery**	**Rationale**
β	Discount Factor	0.9932	0.9900	Match 2.79% & 4.12% mean annual interest rate (2000-2019)
δ	Depreciation of K	0.0186	0.0162	Target mean annual value of K/Y for period 2000-2019 (2.93 & 3.21 for Core & Periphery respectively)
C. Parameters set from Literature		**Core**	**Periphery**	**Rationale**
α	Capital's share of Y	0.3488	0.3550	Mean values for Core & Periphery using Christou et al. (2021), close to Philippopoulos et al. (2017)
σ	Risk aversion coefficient	2	2	Commonly set in the Literature
ϕ	Marginal disutility wrt labor supply	1.5	1.5	Commonly set in the Literature
ϵ^w	Elasticity of subs.between differentiated Jobs	1.05	1.05	Christiano et al. (2005)
ω	Home goods bias in consumption	0.75	0.75	Chodorow-Reich (2019)
D. Shock parameters		**Core**	**Periphery**	**Rationale**
ρ_A	Autoregressive parameter of A	0.846	0.813	OLS autoregression coefficient
σ_A^A	St. deviation of Technological Shock	0.0055	0.0046	St. deviation of OLS residual
σ_{MP}	St. deviation of Monetary Policy Shock	0.0061	0.0061	St. deviation of residual obtained from VAR

Table 4.3: Prior distributions and posterior estimates, for the rational expectations models and models with learning.

			RES(All Mechs)		RES(No Mechs)		Learn(All Mechs)		Learn(No Mechs)	
Par	**Prior**	**Area**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**
θ^W	$B(0.64, 0.1)$	C	0.127	$[0.091, 0.171]$	0.137	$[0.082, 0.191]$	0.856	$[0.76, 0.916]$	0.684	$[0.678, 0.692]$
		P	0.143	$[0.086, 0.207]$	0.147	$[0.102, 0.194]$	0.619	$[0.586, 0.685]$	0.49	$[0.487, 0.495]$
θ^P	$B(0.5, 0.1)$	C	0.111	$[0.045, 0.159]$	0.084	$[0.027, 0.148]$	0.24	$[0.22, 0.256]$	0.211	$[0.208, 0.213]$
		P	0.064	$[0.013, 0.123]$	0.085	$[0.026, 0.157]$	0.188	$[0.178, 0.196]$	0.039	$[0.035, 0.043]$
ϕ_π	$N(1.67, 1)$	B	1.247	$[1.168, 1.338]$	1.638	$[1.543, 1.752]$	1.905	$[1.853, 1.961]$	1.913	$[1.906, 1.929]$
ϕ_Y	$\Gamma(0.14, 0.5)$	B	0.001	$[0, 0.009]$	0.001	$[0, 0.009]$	0.12	$[0.077, 0.157]$	0	$[0, 0.002]$
η	$B(0.7, 0.1)$	C	0.324	$[0.256, 0.395]$			0.507	$[0.371, 0.581]$		
		P	0.965	$[0.944, 0.984]$			0.671	$[0.624, 0.737]$		
ρ_{CB}	$B(0.5, 0.1)$	B	0.426	$[0.361, 0.529]$			0.314	$[0.261, 0.355]$		
γ	$U(0, 1)$	C	0.713	$[0.627, 0.805]$			0.588	$[0.5, 0.639]$		
		P	0.47	$[0.364, 0.582]$			0.422	$[0.357, 0.476]$		
$\bar{g}$	$B(0.03, 0.02)$	C					0.006	$[0.001, 0.018]$	0.031	$[0.023, 0.035]$
		P					0.122	$[0.105, 0.137]$	0.017	$[0.002, 0.028]$

Notes: In the second column about the prior distributions, we use the first letter to characterize the distribution used for each parameter: U stands for uniform, G for Gamma, B for Beta. In the parenthesis of each distribution the mean and standard deviation are mentioned, except for the Uniform prior, for which lower and upper bounds are depicted. Letters C,P,B stand for Core, Periphery and Both respectively. Posterior means and 95% credible intervals have been calculated over 500,000 Metropolis-Hastings draws, discarding a burn-in of 40% draws following Milani (2017).

this range. As regards the coefficients for the Taylor rule, ϕ_π follows a Normal distribution as in Milani (2017), and to restrict ϕ_Y to the range $[0, \infty]$, we let it follow a Gamma distribution. Finally, as regards the constant gain term, it follows a Beta distribution, since it is restricted to the range $[0, 1]$ and the literature assigns relatively low values to this parameter. We set the means of the priors between Core and Periphery equal between them.

Considering the posterior distributions, these are usually well-behaved. We discuss whether the posterior means are sensitive to alternative priors in the Robustness session (6). Table 4.3 summarizes the priors and posterior means for the Bayesian estimation of the parameters, for all the models examined, with RES or Learning and with active mechanisms of persistence or not.

4.2.2 Initialization of values for the learning process

As it is commonly referred to the learning literature, (as discussed by various authors, like for instance Carceles-Poveda and Giannitsarou (2007), Milani (2007) and Milani (2017)) the choice of initial values for the agent's learning process may potentially affect the results. As mentioned in Milani (2017) the preferred initialization can be chosen according to which procedure provides the best performance using as criterion its ability to fit the data. We test five different approaches in setting these initial values. The first is by using the approach of Christiano et al. (2005) in the following way: Using a benchmark model which is basically calibrated to match Core's and Periphery's data, we minimize a measure of the distance between the model and empirical impulse response functions, for the period of interest.[8]

[8]The values for the benchmark calibrated model which are not estimated, but instead are calibrated, are the following: For the Core: $\theta^w = 0.64, \theta^P = 0.16$ and when the mechanisms of persistence are active $\eta = 0.3, \gamma = 1$. For the Periphery:

Second, using the same technique, only for the first 32 periods (2000Q1-2007Q4). Third, using a pre-sampling period (1980Q1-1999Q4) and a calibrated benchmark model, we follow the same technique of Christiano et al. in estimating the initial estimates of the agents and keep the last estimates of 1999Q4. Forth, by estimating the model for the period 1980Q1-1999Q4, using Bayesian estimation, we use the values of rational expectations as initial values for the learning process. Finally, by letting the initial values to target forecasts, as provided by Eurostat.[9] We discuss the relative differences in the robustness section (section 6), however in general our empirical conclusions are robust to different choices of initial beliefs at the beginning of the sample. The graphs and tables presented in the next session are referred to the methodology derived the highest marginal likelihood values, which is the first approach described.

5 Results and discussion

We compare the performance of the models considered in our work, i.e. one model with RE, price and wage rigitidies, habit formation, price indexation and interest rate stickiness, one model with RE with only price and wage rigidities and the respective ones with learning (four models in total). Table 5.1 summarizes the marginal likelihoods and posterior model probabilities of the simulations generated from models with learning and rational expectations. The model with learning, without additional sources of persistence is the one that fits better the data, following by the model with learning, with all mechanisms of persistence active, as in the work of Milani (2017). The posterior probabilities of the models compared indicate that there is no need for adding habit formation, interest rate stickiness and price indexation in the case of the Euro Area, when we examine in pairs both the learning models and the models with RES.

Table 5.1: Log marginal Likelihood and posterior probabilities of each model.

	RES(All Mechs)	**RES(No Mechs)**	**Learn(All Mechs)**	**Learn(No Mechs)**
Log marg. Likelihood	-17.87	-15.44	-9.23	-1.65
	(4.13)	(3.74)	(2.41)	(0.69)
Posterior prob	0.0000	0.0000	0.0005	0.9995

Notes: The log marginal likelihoods are calculated using Geweke's Modified Harmonic Mean approximation.The standard devitation of the log marginal likelihoods are shown in parenthesis.

$\theta^w = 0.64, \theta^P = 0.05$ and when the mechanisms of persistence are active $\eta = 0.3, \gamma = 1$. The values for θ^w are from Christiano et al. (2005) whereas θ^P is calculated from the steady state of the model, using $\epsilon = 1.01$ as in Christiano et al. (2005). For the Taylor rule: $\phi_\pi = 1.67, \phi_Y = 0.14$ as in Smets and Wouters (2003) and when active, $\rho_{CB} = 0.49$ following Brand and Mazelis (2019).

[9] We examined targeting forecasts, only in the case where the monetary shock is obtained as the Taylor rule residual, due to the fact that it requires in each draw of the Bayesian procedure, to minimize the distance between the expectations derived from the model and the forecasts and it would be computationally cumbersome to also obtain the residual from the VAR in each draw.

The constant gain value $\hat{g}$, according to Milani (2007), represents the speed at which agents learn the RES. The reverse of the constant gain value, corresponds to how many quarters, agents of each Area use in their econometric regressions. According to the model with the highest posterior probability, agents of Core take into account 36 quarters (or 3 years) for their learning process, whereas agents of Periphery use 53 quarters (or about 13 years). This suggests that agents in the Core adjust their expectations at a faster pace in comparison to agents of the Periphery, indicating that they are more responsive to new information. This could reflect historical differences in economic stability between the two Areas, or institutional factors, which allows agents to be more keen to new information. Moderately high values of the constant-gain term, allows agents to correct their expectations at a faster pace, hence these evolve more closely to the RE ones, leading eventually at short-term dynamics which are more close to the RE. On the other hand, lower values of the constant gain term leads to a lower pace of correcting the forecasting errors, allowing initial beliefs or other behavioral phenomena (like animal spirits, not examined in this work) to play a major role in short-term macroeconomic dynamics.

Figures 5.1 and 5.2 illustrate the simulations generated for output, investment, inflation, labor, consumption and wages. We notice that the models with learning, better capture the boom and bust periods of the Periphery, whereas the RE models perform equally well in comparison to the models with learning for the case of the output of Core.

Figure 5.1: Simulation results generated by the four models into consideration for key variables examined, for Core, in comparison to the detrended data.

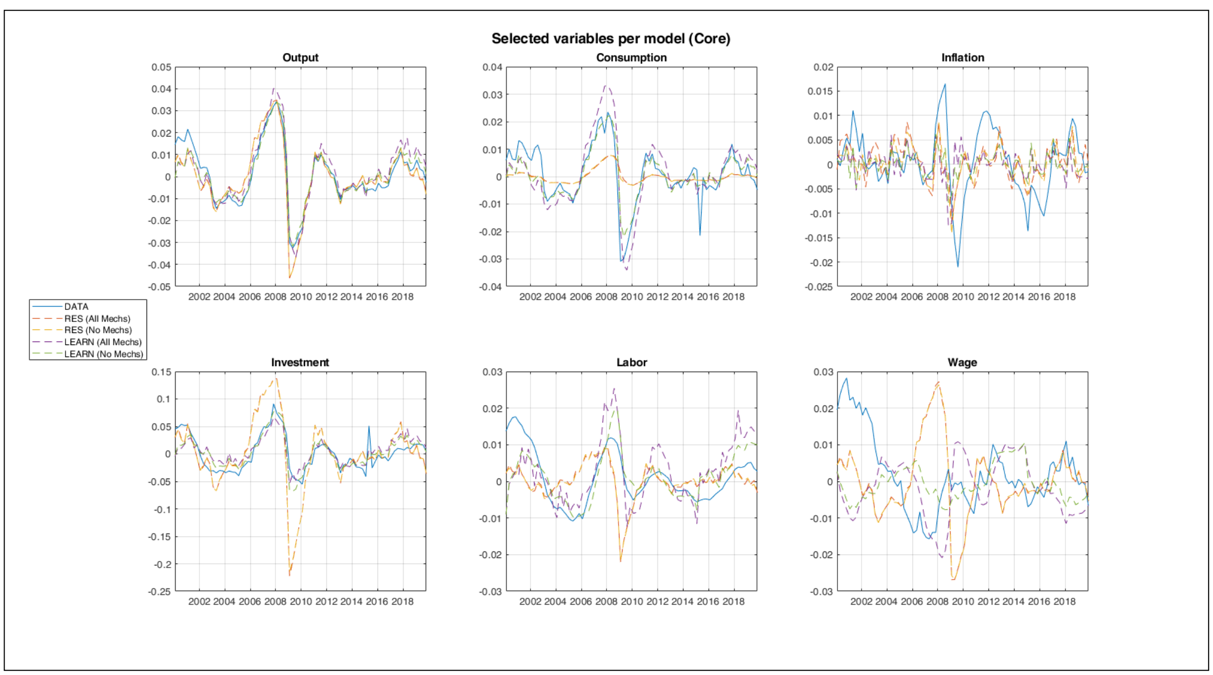
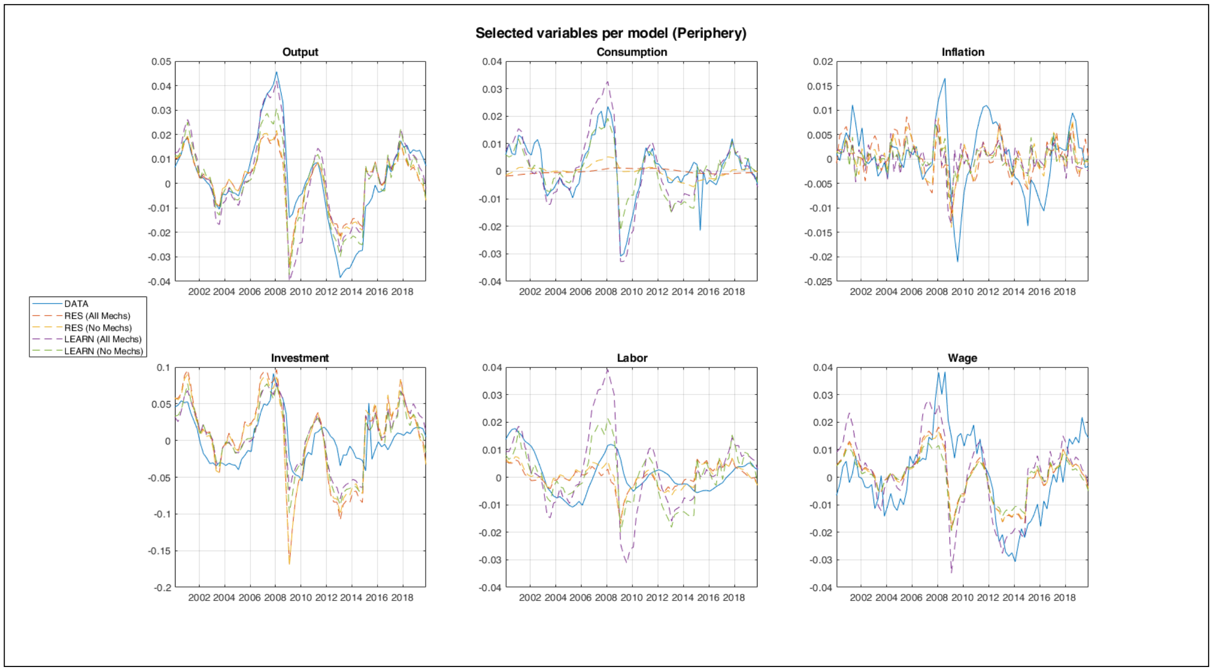


Figure 5.2: Simulation results generated by the four models into consideration for key variables examined, for Periphery, in comparison to the detrended data.



We move forward into our analysis to further examine whether there are any policy implications from the presence of learning. In particular we examine whether a Central Bank who aims to minimize the associate welfare costs from output and inflation volatility should take into account learning or not. Orphanides and Williams (2005) find that optimal policy is more robust when the policy is focused on inflation stabilization. We take, as it is standard, a quadratic welfare cost function of the form: [10]

$$L = \frac{1}{2}\left\{\sum_{t=0}^{\infty}\beta^t\left[q\left(w^C(y_t^C-\bar{y}^C)^2+w^P((y_t^P-\bar{y}^P))^2\right)+w^C(\pi_t^C-\bar{\pi}^C)^2+w^P(\pi_t^P-\bar{\pi}^P)^2\right]\right\} \tag{61}$$

where q is the relative preference of the Central bank to output stabilization. The quadratic loss function takes into consideration the weighted average of the respective losses from destabilizing output and inflation of Core and Periphery. We aim to find the optimized inflation and output gap weights of the Taylor rule that minimize the welfare loss function, in the case of the rational expectations model (without habit formation and other sources of persistence as we showed up earlier that these mechanisms are redundant in the case of the Eurozone) and in the case of learning, for various values of q. Table 5.2 summarizes the results. As we can observe, for relatively low values of q ($q < 0.2$), which indicates a Central Bank that is mainly focused on stabilizing inflation, the Central Bank should react more intense in stabilizing inflation in the learning case, in comparison to the Rational expectations

[10] See among others, Evans and Honkapohja (2003), Ferrero (2007), Galí (2007)

case. In particular, we find that, whereas in the case of rational expectations the optimized weights for the inflation and output gap are 1.25 and 0 respectively, for the case of learning the corresponding values are 3.65 and 0. This finding is in line with Orphanides and Williiams (2005) and Chortareas et al. (2012), i.e. the central bank may need to prioritize inflation stabilization to a greater extent in order to maintain economic stability. This could help agents of the economy who are gradually learning, to anchor their expectations about inflation, avoiding actions which can be more volatile and could potentially lead to greater fluctuations in the economy. A stronger reaction to inflation in comparison to the RE case is explained by the fact that this leads to a higher difference between agent's expectations and realization, and a larger forecasting error will make the agents to correct at a faster pace their expectations, making expected inflation to be more close to the RE, as discussed in Ferrero (2007).

On the other hand, when ($q \geq 0.2$) which indicates that the policymaker is also interested in maintaining output stability, in the case of learning, the optimized response is to react moderately to inflation and mildly to output. Comparing this reaction with the respective one in the RE case, according to our results, the slight reaction to output (0.05) leads to a moderate, but stronger reaction to inflation, in comparison to the RE. This could highlight the need for the central bank to maintain a balance between inflation and output stabilization, but still by responding more intense to inflation in relevance to output. As a result, the optimal policy response becomes more moderate for the inflation gap, indicating that the central bank should not react as intensely as in the case without considering the output gap. We discuss the sensitivity of the monetary policy implications to the way that the exogenous monetary policy shock is obtained in the next session.

Table 5.2: Optimized Taylor rule coefficients per relative output gap preference

q	ϕ_π		ϕ_Y	
	R	L	R	L
0	1.25	3.05	0	0
0.05	1.25	3.65	0	0
0.15	1.25	3.65	0	0
0.2	1.25	1.35	0	0.05
0.5	1.25	1.35	0	0.05
1	1.25	1.35	0	0.05

Notes: We have investigated the optimized Taylor rule coefficients within the range $1 \leq \phi_\pi \leq 8$, and $0 \leq \phi_\pi \leq 8$. R stands for the model with rational expectations and L for learning. Both models do not include additional sources of persistence, as they both perform better without them.

6 Robustness analysis

This section discusses the sensitivity of the main results to a range of alternative specifications. First, the choice of detrending filter could potentially affect the results. We tested whether our main findings, considering the performance of the learning models versus the rational expectations changes under different filters. We used as alternatives to the HP filter with $\lambda = 6400$, a value for $\lambda = 1600$, the Hamilton filter and a simple linear detrending filter, without affecting the ranking of the performance of the models considered in our analysis.

As regards the priors chosen for the Bayesian estimation, we examine whether an alternative selection could alter the posterior means significantly. For this scope, we allowed the priors to be rather uninformative, as we allow price stickiness, wage stickiness, interest rate stickiness and habit formation to follow a Uniform distribution. Furthermore, Taylor rule coefficients follow Normal distributions with relatively high standard deviation (1 and 0.5 respectively). Finally, we also allow the constant gain term to follow a Uniform distribution in $(0, 0.2]$, as the related literature usually reports values at low ranges (usually 0.001 to 0.07). We report the relative prior and posterior means values for the models examined in A.5.1. Letting the data determine the values for the various stickiness mechanisms, neither alters the main conclusions driven (table A.3), considering which model provides the best fit, nor provides posterior means significantly different from the ones reported in table A.6 considering the parameters of interest for our analysis, like the constant-gain term for Core and Periphery. However, we notice that in this case, the wage stickiness in the RE models shrinks to 0, whereas the price stickiness increases relatively to previous values reported.

We further examine the sensitivity of our results to the values of σ,ϕ and ω. To test this, we allow these parameters to be also fitted using the data, in all models examined, and evaluate whether the performance of the models changes or the values of the parameters change significantly. The posterior means and the log marginal Likelihood are illustrated in tables A.6 and A.7 respectively. When allowing these parameters to be jointly estimated with the stickiness parameters, we notice that in the RE case, the significance of wage and price stickiness increase in comparison to the results noted earlier. As regards the models with learning, the values of the parameters are close to the original reported. More importantly, we can observe that neither the performance ranking of the models examined, nor the constant-gain value are affected significantly enough to change the main conclusions derived in our paper. In general, adding these parameters to the estimation procedure, does not lead to an improve of the fitting of the models examined.

Considering the identification procedure for obtaining the exogenous monetary policy shock, we have further tested our results for different identification methodologies. In particular we tested obtaining the exogenous monetary policy shock using a simple VAR with output, inflation and central bank's interest rate with 4 and 8 lags. The conclusions derived, considering the fitness performance of the models examined and the constant gain value for each area are maintained. As regards the optimized responsiveness of the policymaker in deviations of output and inflation, table A.5 summarizes the resuls. We can observe that the optimized behavior in the RE case changes, as now it is suggested that the central bank to respond to deviations of output, even in low values of q. However, in the case of learning, it is never optimal for the policymaker to respond to output, even moderately, regardless of the values of q. This highlights the need to anchor inflation expectations, in the case of learning, indicating that the policymaker should respond intensively to inflation, in line with the conclusions derived in Orphanides and Williiams (2005).

As regards the importance of initial conditions in the learning process, table A.4 summarizes the log-marginal likelihoods per each methodology examined. It is reasonable that the methodologies with learning that derives the best fit are the ones that use a benchmark model, for the period examined (2000Q1-2019Q4). However, as it can be observed from table A.4, learning outperforms the rational expectations models, in all the initialization methods examined. However, we perform an additional exercise, following the work of Eusepi and Preston (2011). In particular, we move away from the Bayesian estimation and by targeting the volatility of HP-detrended output and the first autocorrelation coefficient of output growth, we calibrate the standard deviation of the technological shock, $\sigma^{a,A}$ and the constant gain term, $\bar{g}$. Then we compare the 2nd-moment properties with the respective ones obtained by the RE model, with and without sources of persistence.[11]We draw 580 random simulations and keep the last 80, to be in line with the duration of the period of interest (2000Q1-2019Q4). Using this approach, we confirm the finding of the work of Eusepi and Preston considering the improvement of the matching of the movements in most of the variables examined, as presented in tables A.8 -A.11. We further confirm the second main result of their work, that the standard deviation of the technology shock is significantly lower in comparison to the RE case. In particular, we find that in the case of learning without further mechanisms of persistence, the st. deviation is 13% and 15% lower for the Core and Periphery respectively, in comparison to the respective model with RE (the corresponding values for the models with additional sources of persistence are 7% and 6%).

Finally, we examine whether our conclusion considering the optimized reaction of the policy-maker in the Euro Area, under learning, is sensitive to the way initial beliefs are set. For this scope, we use as an alternative methodology, to set initial beliefs using a presampling period (1980Q1-1999Q4), as described in section 4.2.2. In this case, the reaction of the policy maker towards inflation should be even more aggressive (for $q \geq 0.15$, $\phi_\pi > 4$) and as q value increases, the policy-maker should react

[11]In the RE models, we target the same properties, by calibrating the parameters $\sigma^{a,A}$ and the autocorrelation coefficient of the technological processes, which the model with learning take then as given.

moderately intense towards narrowing the output gap (the maximum value for ϕ_Y is 0.65 when $q = 1$).

7 Conclusions

This paper focused on the role of learning in explaining the discrepancies in the magnitude of the boom and bust cycles of Core and Periphery in the Eurozone. Using Bayesian estimation and second moment analysis following the works of Milani (2007) and Eusepi and Preston (2011) respectively, we find that learning helps to fit the data. Furthermore, by comparing the posterior probabilities of the models examined in our work, we find that additional sources of persistence like habit formation, interest rate stickiness and price indexation become redundant, as in the respective work of Milani (2007) for the case of US. Finally, we conclude that a monetary authority that aims to minimize the welfare losses associated with output and inflation volatility, should react more intense to stabilize inflation, in comparison to when only rational expectations are considered, in line with the conclusions provided in the work of Orphanides and Williams (2008).

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A Appendix

A.1 Graphs of data for Core and Periphery

Figure A.1 depicts the data for key variables of the model for the period examined (2000Q1-2019Q4), for Core and Periphery, as calculated using the available data described in session 4.1.

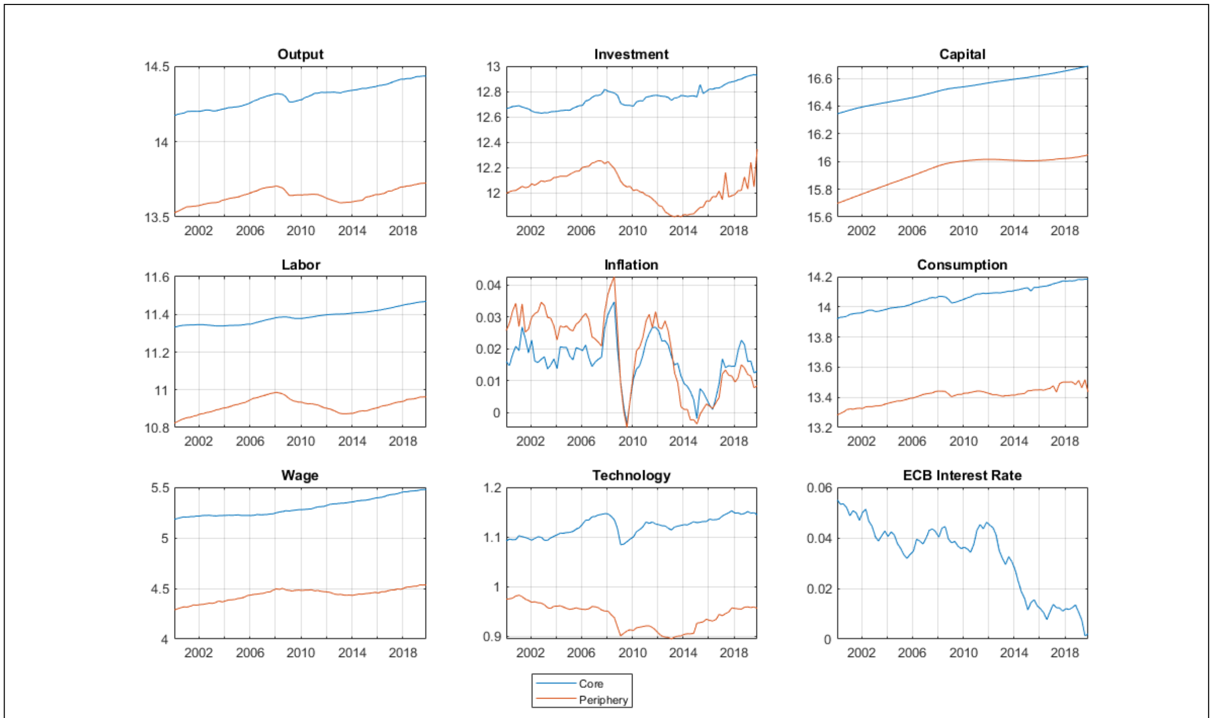

Figure A.1: Data series constructed for Core and Periphery. Notes: output, investment, capital, consumption and wage are all expressed in real terms and are reported in log levels. Interest rate and inflation are in levels.Technology is obtained as the Solow residual and reported in log-levels.

A.2 Deriving the Marginal Cost of the Wholesale Firm

From (38), rearranging the terms, labor can be written as:

$$L_{j,t} = \frac{1-\alpha}{\alpha} \frac{R_t^k}{W_t} K_{j,t} \tag{62}$$

Then, by substituting eq. 62 into the production function, we can solve for $K_{j,t}$:

$$K_{j,t} = \frac{Y_{j,t}}{A_t} \left[\left(\frac{\alpha}{1-\alpha} \frac{W_t}{R_t^k} \right) \right]^{1-\alpha} \tag{63}$$

Using (63) into (62) we can get an expression for labor, as a function of technology, wholesaler's output and the prices of the producing factors:

$$L_{j,t} = \frac{Y_{j,t}}{A_t} \left[\left(\frac{\alpha}{1-\alpha} \right) \frac{W_t}{R_t^k} \right]^{-\alpha} \tag{64}$$

Total cost in our case equals:

$$\begin{aligned} TC_{j,t} &= W_t L_{j,t} + R_t^k K_{j,t} \\ \Rightarrow TC_{j,t} &= W_t \frac{Y_{j,t}}{A_t} \left[\left(\frac{\alpha}{1-\alpha} \right) \frac{W_t}{R_t^k} \right]^{-\alpha} + R_t^k \frac{Y_{j,t}}{A_t} \left[\left(\frac{\alpha}{1-\alpha} \frac{W_t}{R_t^k} \right) \right]^{1-\alpha} \\ TC_{j,t} &= \frac{Y_{j,t}}{A_t} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t^k}{\alpha} \right)^{\alpha} \end{aligned} \tag{65}$$

Hence, taking the derivative of (65) wrt $Y_{j,t}$ will give us the marginal cost of wholesale firm j:

$$MC_{j,t} = \frac{\vartheta TC_{j,t}}{\vartheta Y_{j,t}} = \frac{1}{A_t} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t^k}{\alpha} \right)^{\alpha}$$

A.3 The Static Model

The decentralized equilibrium equations in the steady state will be:

Household's budget constraint:

$$\frac{P^{H,A}}{P^A}C^{H,A}+\frac{P^{F,A}}{P^A}C^{F,A}+\frac{B^A}{P^A R^{B,A}}+\delta K^A=\frac{B^A}{P^A}+\frac{W^A}{P^A}L^A+\frac{R^{k,A}}{P^A}K^A+\frac{\Pi^A}{P^A} \tag{S.1}$$

where $A=\{C,P\}$ for Core and Periphery respectively.

Law of Motion for Capital:

$$I^A=\delta K^A \tag{S.2}$$

Household's Consumption Bundle:

$$C^A=\frac{(C^{H,A})^{\omega}(C^{F,A})^{1-\omega}}{\omega^{\omega}(1-\omega)^{1-\omega}} \tag{S.3}$$

Total Consumption Expenditure:

$$P^A C^A=P^{H,A}C^{H,A}+P^{F,A}C^{F,A} \tag{S.4}$$

Law of one Price:

$$\begin{aligned} P^{F,C}&=ZP^{H,P}\\ P^{F,P}&=ZP^{H,C} \end{aligned} \tag{S.5}$$

FOC wrt C_t^H:

$$\frac{P^{H,A}}{P^A}\lambda^A=\frac{\omega(C^{H,A})^{\omega-1}(C^{F,A})^{(1-\omega)}}{\omega^{\omega}(1-\omega)^{(1-\omega)}}(1-\eta\beta)((1-\eta)C^A)^{-\sigma} \tag{S.6}$$

FOC wrt C_t^F:

$$\frac{P^{F,A}}{P^A}\lambda^A=\frac{(C^{H,A})^{\omega}(1-\omega)(C^{F,A})^{-\omega}}{\omega^{\omega}(1-\omega)^{(1-\omega)}}(1-\eta\beta)((1-\eta)C^A)^{-\sigma} \tag{S.7}$$

Euler I:

$$1=\beta R^{B,A} \tag{S.8}$$

Euler II:

$$1 = \beta\left(1 - \delta + \frac{R^{k,A}}{P^A}\right) \tag{S.9}$$

Optimal Wage:

$$\frac{W^{\star,A}}{P^A} = \left(\frac{\varepsilon_w^A}{\varepsilon_w^A - 1}\right)\frac{\Phi^A L^A}{(1 - \beta^A\theta_w^A)\lambda^A} \tag{S.10}$$

Gross Wage Inflation Rate:

$$\pi_w^A = \frac{W^A}{W^A} = 1 \tag{S.11}$$

Gross Inflation Rate:

$$\pi^A = \frac{P^A}{P^A} = 1 \tag{S.12}$$

Aggregate Wage:

$$\begin{aligned} W^A = \theta_w^A &\left(\pi^A W^A)^{1/(1-\varepsilon_w^A)} + (1 - \theta_w^A)(W^{*,A})^{1/(1-\varepsilon_w^A)}\right)^{(1-\varepsilon_w^A)} \\ \Rightarrow (1 - \theta_w^A)(W^A)^{1/(1-\varepsilon_w^A)} &= \left((1 - \theta_w^A)(W^{*,A})^{1/(1-\varepsilon_w^A)}\right) \\ \Rightarrow W^A &= W^{\star,A} \end{aligned} \tag{S.13}$$

Demand for capital:

$$\frac{R^{k,A}}{P^A} = \alpha^A \frac{MC^A}{P^A}\frac{Y^A}{K^A} \tag{S.14}$$

Demand for Labor:

$$\frac{W^A}{P^A} = (1 - \alpha^A)\frac{MC^A}{P^A}\frac{Y^A}{L^A} \tag{S.15}$$

Optimal Price:

$$P^{\star,A} = \frac{\varepsilon_c^A}{(\varepsilon_c^A - 1)}\frac{1}{(1 - \beta^A\theta^A)}MC^A \tag{S.16}$$

General Price Level:

$$P^A = P^{\star,A} \tag{S.17}$$

Marginal Cost of Wholesaler's firm:

$$\frac{MC^A}{P^A} = \frac{1}{A^A} \left(\frac{W^A/P^A}{1-\alpha^A} \right)^{1-\alpha^A} \left(\frac{R^{k,A}/P^A}{\alpha^A} \right)^{\alpha^A} \tag{S.18}$$

Wholesaler's Profits:

$$\frac{\Pi^A}{P^A} = Y^A \left(1 - \frac{MC^A}{P^A} \right) \tag{S.19}$$

Equilibrium Condition:

$$Y^A = C^A + I^A \tag{S.20}$$

Resource Constraint:

$$Y^A = A^A K^{\alpha^A} L^{1-\alpha^A} \tag{S.21}$$

Evolution of Technology (Set):

$$A^A = 1 \tag{S.22}$$

A.4 Deriving the reduced form log-linearized Model

In order to derive the reduced, log-linearized (1st order) form of the model, some further mathematical manipulations are required. In particular, the model can be written as a function only of $\{y_t, k_t, c_t, w_t, \pi_t, R_t^{CB}, a_t, s_t\}$. First, from the budget constraint (eq. 14) the quantity of bonds can be derived, only as a function of the aforementioned variables. Second, replace L_t from the production function (eq. 33) to get:

$$L_t = Y_t^{\frac{1}{1-\alpha}} A_t^{\frac{-1}{1-\alpha}} K_t^{\frac{-\alpha}{1-\alpha}} = \left(\frac{Y_t}{A_t K_t^{\alpha}}\right)^{\frac{1}{1-\alpha}} \tag{RF.1}$$

Then, the log-linearized labor, $\hat{l_t}$ will be:

$$\hat{l_t} = \frac{1}{(1-\alpha)}(\hat{y_t} - \hat{a_t} - \alpha\hat{k_t}) \tag{RF.2}$$

Third the real rent of capital, using eqs. (38) and (RF.1), can be written as:

$$\frac{R_t^k}{P_t} = \frac{\alpha}{1-\alpha}\frac{L_t}{K_t}\frac{W_t}{P_t}$$
$$\Rightarrow \frac{R_t^k}{P_t} = \frac{\alpha}{1-\alpha}\left(\frac{Y_t}{A_t K_t^{\alpha}}\right)^{\frac{1}{1-\alpha}} \frac{W_t}{K_t P_t} \tag{RF.3}$$

Thus, the log-linearized real rent of capital, $\hat{r_t^k}$ will be:

$$\hat{r_t^k} = \frac{1}{(1-\alpha)}(\hat{y_t} + \hat{a_t} - (\alpha+1)\hat{k_t}) + \hat{w_t} \tag{RF.4}$$

As regards the real marginal cost, using eq. 39 and eq. RF.3 we can get:

$$\frac{MC_t}{P_t} = \frac{1}{A_t}\left(\frac{W_t/P_t}{1-\alpha}\right)^{(1-\alpha)}\left(\frac{\alpha W_t/P_t}{\alpha(1-\alpha)K_t}\left(\frac{Y_t}{A_t K_t^{\alpha}}\right)^{\frac{1}{1-\alpha}}\right)^{\alpha}$$
$$\Rightarrow \frac{MC_t}{P_t} = \frac{1}{(1-\alpha)}\left(\frac{W_t}{P_t}\right) Y_t^{\frac{\alpha}{1-\alpha}} A_t^{\frac{-1}{1-\alpha}} K_t^{\frac{-\alpha}{1-\alpha}} \tag{RF.5}$$

Hence, the log-linearized, real marginal cost, $\hat{mc_t}$ will be:

$$\hat{mc_t} = \hat{w_t} + \left(\frac{\alpha}{1-\alpha}\right)\hat{y_t} + \left(\frac{-1}{1-\alpha}\right)\hat{a_t} + \left(\frac{-\alpha}{1-\alpha}\right)\hat{k_t} \tag{RF.6}$$

As regards the log-linearized first order conditions of the consumption of domestic goods and imported goods, these are as follows:

$$\frac{p_{ss}^{H,A}\lambda_{ss}^{A}}{P_{ss}^{A}}\left(p_t^{H,A}+\lambda_t^A-p_t^A\right)=q_{H,A}[(1+\beta\eta_A^2)c_t^A+(-\eta_A)c_{t-1}^A+(-\eta_A\beta)E_tc_{t+1}^A]+z_{H,A}\left[(\omega_A-1)c_t^{H,A}+(1-\omega_A)c_t^{F,A}\right] \tag{RF.7}$$

$$\frac{p_{ss}^{F,A}\lambda_{ss}^{A}}{P_{ss}^{A}}\left(p_t^{F,A}+\lambda_t^A-p_t^A\right)=q_{F,A}[(1+\beta\eta_A^2)c_t^A+(-\eta_A)c_{t-1}^A+(-\eta_A\beta)E_tc_{t+1}^A]+z_{F,A}\left[\omega_Ac_t^{H,A}+(-\omega_A)c_t^{F,A}\right] \tag{RF.8}$$

Using the total consumption expenditure, household's consumption bundle and the law of one price for the home country (denoted with H) we get that:

$$\begin{aligned}
(p_{ss}^Hc_{ss}^H)(p_t^H+c_t^H) &= (p_{ss}^{H,H}c_{ss}^{H,H})(p_t^{H,H}+c_t^{H,H})+(p_{ss}^{H,F}c_{ss}^{H,F})(p_t^{H,F}+c_t^{H,F})\\
&= (p_{ss}^{H,H}c_{ss}^{H,H})(p_t^{H,H}+c_t^{H,H})+(p_{ss}^{H,F}c_{ss}^{H,F})\left(p_t^{H,F}+\frac{c_t^H-\omega_Hc_t^{H,H}}{(1-\omega_H)}\right)\\
\Rightarrow p_t^{H,H} &= \left(\frac{p_{ss}^Hc_{ss}^H}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)p_t^H+\left(\frac{-p_{ss}^{H,F}c_{ss}^{H,F}}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)p_t^{H,F}+\left(\frac{p_{ss}^Hc_{ss}^H-\frac{p_{ss}^{H,F}c_{ss}^{H,F}}{1-\omega_H}}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)c_t^H+\left(\frac{p_{ss}^{H,H}c_{ss}^{H,H}-\frac{p_{ss}^{H,F}c_{ss}^{H,F}}{1-\omega_H}}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)c_t^{H,H}\\
\Rightarrow p_t^{H,H} &= \left(\frac{p_{ss}^Hc_{ss}^H}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)p_t^H+\left(\frac{-p_{ss}^{H,F}c_{ss}^{H,F}}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)p_t^{H,F} \qquad \text{(RF.9)}
\end{aligned}$$

where p_t^H is the general price level of the home area (Core and Periphery), $p_t^{H,H}$ is the price for domestic tradable goods, $p_t^{H,H}$ is the price for imported tradable goods, c_t^H the consumption of the home area, $c_t^{H,H}$ the consumption of home goods and $c_t^{H,F}$ the consumption of imported goods. Define:

$$p_{1,C}\equiv\left(\frac{p_{ss}^Hc_{ss}^H}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)$$

$$p_{2,C}\equiv\left(\frac{-p_{ss}^{H,F}c_{ss}^{H,F}}{p_{ss}^{H,H}c_{ss}^{H,H}}\right)$$

Since:

$$p_{ss}^Hc_{ss}^H\simeq p_{ss}^{H,H}c_{ss}^{H,H}\simeq\frac{p_{ss}^{H,F}c_{ss}^{H,F}}{1-\omega_H}$$

then, by combining eqt (RF.9) for the two areas, the domestic price level for each area can be written as a function only of the general price level of the two areas:

$$p_t^{H,H} = p_3 p_t^H + p_4 p_t^F \tag{RF.10}$$

where p_t^F is the general price level of the foreign area and:

$$p_3 = \frac{(p_{ss}^C c_{ss}^H) - (p_{ss}^{H,F} c_{ss}^{H,F}) \left(\left(1 - \frac{(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^{H,F} c_{ss}^{H,F})}{(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^{H,F} c_{ss}^{H,F})}\right)^{(-1)} \right) \left(\frac{-(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^H c_{ss}^H)}{(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^{H,F} c_{ss}^{H,F})} \right)}{(p_{ss}^{H,H} c_{ss}^{H,H})}$$

$$p_4 = \frac{-(p_{ss}^{H,F} c_{ss}^{H,F}) \left(\left(1 - \frac{(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^{H,F} c_{ss}^{H,F})}{(p_{ss}^{H,H} c_{ss}^{H,H})(p_{ss}^{H,F} c_{ss}^{H,F})}\right)^{(-1)} \right) \frac{(p_{ss}^{H,F} c_{ss}^{H,F})}{(p_{ss}^P c_{ss}^P)}}{(p_{ss}^{H,H} c_{ss}^{H,H})}$$

The variables $c_t^{H,A}$ and $\lambda_t^{H,A}$ can be eliminated from the model using the following procedure: First define $\widetilde{c_t} \equiv (c_t - \eta c_{t-1}) - \beta_A \eta_A (E_t c_{t+1} - c_t)$. Then, since we have that:

$$p_{ss}^{H,A} = p_{ss}^{F,A}$$

and due to the fact that:

$$q_{H,A} = q_{F,A}$$

$$z_{H,A} = z_{F,A}$$

then, by subtracting RF.8 from RF.7 the λ term is removed and we get:

$$c_t^{H,A} = (1 - \omega_A) \left(\frac{p_{ss}^{H,A} \lambda_{ss}^A}{p_{ss}^A z_{H,A}} \right) (p_t^{F,A} - p_t^{H,A}) + c_t^A \tag{RF.11}$$

Finally, after having solve for $c_t^{H,A}$ and since $c_t^{F,A}$ can be easily found from household's consumption expenditure, λ_t^A can be found by either using eq. (RF.7) or eq. (RF.8) and thus, to also be eliminated from the remaining unknowns. Hence, all unknowns can be expressed as a function of the variables $\{y_t^A, w_t^A, c_t^A, \pi_t^A, k_t^A, r_t^{CB}, a_t^A\}$. Table A.1 summarizes the reduced form model, which consists of 13 equations in 13 unknowns $\{y_t^C, y_t^P, w_t^C, w_t^P, c_t^C, c_t^P, \pi_t^C, \pi_t^P, k_t^C, k_t^P, r_t^{CB}, a_t^C, a_t^P\}$.

Table A.1: Reduced form of log-linearized model

Equation	Definition
$\left(\frac{p^H_{ss}}{p^{H,A}_{ss}\lambda^A_{ss}} q_{H,A}\right)(\widetilde{c^A_t} - \widetilde{E_t c^A_{t+1}}) = ((1-\rho_{CB})(\phi_\pi \pi^A_t + \phi_Y y^A_t + \phi_W(w^A_t - w^A_{t-1} + \pi^A_t)) + \rho_{CB} r^B_{t-1} + S_t)$	Euler I
$\left(\frac{p^H_{ss}}{p^{H,A}_{ss}\lambda^A_{ss}} q_{H,A}\right)(\widetilde{c^A_t} - \widetilde{E_t c^A_{t+1}}) = \beta^A(r^{k,A}_{ss}((\frac{1}{(1-\alpha^A)})E_t y_{(t+1)} + (\frac{-1}{(1-\alpha^A)})r_A A^A_t + (\frac{-1}{(1-\alpha^A)})k^A_t + E_t w^A_{t+1}$	Euler II
$\pi^A_t - \pi^A_{t-1} = \beta^A(E_t \pi_{t+1} - \pi_t) + \kappa_A \left(w^A_t + \left(\frac{-1}{(1-\alpha^A)}\right))A^A_t + \left(\frac{\alpha^A}{(1-\alpha^A)}\right) y^A_t + \left(\frac{-\alpha^A}{(1-\alpha^A)}\right))k^A_t\right)$	NK Phillips Curve
$w^A_t - w^A_{t-1} + \pi^A_t - \beta^A(E_t w^A_{t+1} - w^A_t + E_t \pi^A_{t+1}) = ...$ $= \kappa^w_A \left(-\left(\frac{p^H_{ss}}{p^{H,A}_{ss}\lambda^A_{ss}} q_{H,A}\right)\widetilde{c^A_t} - w^A_t + \phi_A \left(\left(\frac{-1}{(1-\alpha^A)}\right) A^A_t + \left(\frac{1}{(1-\alpha^A)}\right) y^A_t + \left(\frac{-\alpha^A}{(1-\alpha^A)}\right) k^A_t\right)\right)$	Phillips eq. for Wages
$y^A_t = \frac{c^A_{ss}}{y^A_{ss}} c^A_t + \frac{k^A_{ss}}{y^A_{ss}} k^A_{t+1} - (1-\delta_A)\frac{k^A_{ss}}{y^A_{ss}} k^A_t$	Equilibrium Condition
$r^{CB}_t = \rho_{CB} r^B_{t-1} + (1-\rho_{CB})(\phi_\pi(w_C \pi^C_t + w_P \pi^P_t) + ...$ $+\phi_Y(w_C y^C_t + w_P y^P_t) + \phi_W(w_C(w^C_t - w^C_{t-1} + \pi^C_t) + w_P(w^P_t - w^P_{t-1} + \pi^P_t)) + \varepsilon^s_t$	Taylor Rule
$a^A_t = \rho_{a,A} a^A_{t-1} + \varepsilon^{a,A}_t$	Evolution of Technology

Notes: $\widetilde{c^A_t} \equiv (c^A_t - \eta c^A_{t-1}) - \beta_A \eta_A \left(E_t c^A_{t+1} - c^A_t\right)$

A.5 Additional tables for robustness analysis

A.5.1 Alternative priors specification

Table A.2: Prior distributions and posterior estimates, for the rational expectations models and models with learning, in the case where priors are less informative.

			RES(All Mechs)		RES(No Mechs)		Learn(All Mechs)		Learn(No Mechs)	
Par	**Prior**	**Area**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**
θ^W	$U(0,1)$	C	0.026	$[0.001, 0.103]$	0.021	$[0.001, 0.069]$	0.886	$[0.864, 0.914]$	0.678	$[0.66, 0.69]$
		P	0.034	$[0.001, 0.124]$	0.038	$[0.001, 0.133]$	0.724	$[0.71, 0.737]$	0.465	$[0.451, 0.481]$
θ^P	$U(0,1)$	C	0.349	$[0.302, 0.416]$	0.352	$[0.304, 0.4]$	0.23	$[0.222, 0.24]$	0.203	$[0.196, 0.209]$
		P	0.341	$[0.295, 0.384]$	0.343	$[0.273, 0.392]$	0.185	$[0.176, 0.191]$	0.07	$[0.061, 0.078]$
ϕ_π	$N(1.67, 1)$	B	0.994	$[0.801, 1.243]$	2.182	$[2.037, 2.365]$	1.733	$[1.708, 1.746]$	1.741	$[1.733, 1.754]$
ϕ_Y	$N(0.14, 0.5)$	B	−0.254	$[-0.322, -0.191]$	−0.584	$[-0.682, -0.473]$	0.1	$[0.08, 0.128]$	0.037	$[0.009, 0.066]$
η	$U(0,1)$	C	0.099	$[0.004, 0.219]$			0.424	$[0.405, 0.44]$		
		P	0.975	$[0.954, 0.989]$			0.77	$[0.753, 0.781]$		
ρ_{CB}	$U(0,1)$	B	0.247	$[0.071, 0.401]$			0.418	$[0.407, 0.427]$		
γ	$U(0,1)$	C	0.024	$[0.001, 0.066]$			0.424	$[0.406, 0.442]$		
		P	0.039	$[0.001, 0.15]$			0.425	$[0.396, 0.438]$		
$\bar{g}$	$U(0, 0.2)$	C					0.003	$[0, 0.009]$	0.031	$[0.009, 0.047]$
		P					0.124	$[0.108, 0.142]$	0.027	$[0.015, 0.041]$

Notes: In the second column about the prior distributions, we use the first letter to characterize the distribution used for each parameter: U stands for uniform, G for Gamma, B for Beta. In the parenthesis of each distribution the mean and standard deviation are mentioned, except for the Uniform prior, for which lower and upper bounds are depicted. Letters C,P,B stand for Core, Periphery and Both respectively. Posterior means and 95% credible intervals have been calculated over 500,000 Metropolis-Hastings draws, discarding a burn-in of 40% draws following Milani (2017).

Table A.3: Log marginal Likelihood and posterior probabilities of each model, for the alternative prior specification.

	RES(All Mechs)	**RES(No Mechs)**	**Learn(All Mechs)**	**Learn(No Mechs)**
Log marg. Likelihood	−10.78	−5.36	−5.72	−2.66
	(2.32)	(1.78)	(1.69)	(1.03)
Posterior prob	0.0000	0.0601	0.0419	0.8977

Notes: The log marginal likelihoods are calculated using Geweke's Modified Harmonic Mean approximation.The standard devitation of the log marginal likelihoods are shown in parenthesis.

A.5.2 Alternative methodologies for setting initial conditions for learning process

Table A.4: Log marginal Likelihood per each methodology for setting initial conditions for learning process.

Model	Method	Log-Marginal likelihood
RES (No Mechs)	-	-15.44
RES (All Mechs)	-	-17.87
Learn (No Mechs)	Within-sample estimation (2000Q1-2019Q4)	-1.65
Learn (All Mechs)	Within-sample estimation (2000Q1-2019Q4)	-9.22
Learn (No Mechs)	Within-sample estimation (2000Q1-2007Q4)	-3.86
Learn (All Mechs)	Within-sample estimation (2000Q1-2007Q4)	-24.15
Learn (No Mechs)	Presample estimation (1980Q1-1999Q4)	-7.01
Learn (All Mechs)	Preample estimation (1980Q1-1999Q4)	-10.72
Learn (No Mechs)	Target forecasts	-7.62
Learn (All Mechs)	Target forecasts	-5.27

Notes: All estimations have been implemented using the methodology of Christiano et al. (2005) and a benchmark model, as described in footnote 8.The forecasts have been obtained from the official European commission reports per quarter when available.They are usually avaible during each 2nd and 4rth quarter of the year, hence as regards quarters 1 and 3, these are the mean values of 1 quarter ahead, and 1 quarter back.

A.5.3 Different identification procedures for the exogenous monetary policy shock and optimized Taylor rule coefficients

Table A.5: Optimized Taylor rule coefficients per relative output gap weight

q:	0				0.05				0.15				0.2				0.5				1			
	ϕ_π		ϕ_Y		ϕ_π		ϕ_Y		ϕ_π		ϕ_Y		ϕ_π		ϕ_Y		ϕ_π		ϕ_Y		ϕ_π		ϕ_Y	
Identification Method	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
VAR with Taylor rule resid.	1.25	3.05	0.00	0.00	1.25	3.65	0.00	0.00	1.25	3.65	0.00	0.00	1.25	1.35	0.00	0.05	1.25	1.35	0.00	0.05	1.25	1.35	0.00	0.05
VAR without Taylor rule resid. (4 lags)	8.00	8.00	0.05	0.00	8.00	1.85	0.60	0.00	6.00	1.85	1.00	0.00	5.00	1.85	1.50	0.00	3.95	1.85	2.00	0.00	2.65	1.85	2.50	0.00
VAR without Taylor rule resid. (8 lags)	8.00	8.00	0.00	0.00	8.00	2.00	0.20	0.00	8.00	1.95	0.55	0.00	8.00	1.95	0.75	0.00	4.85	1.30	1.00	0.05	5.00	1.30	2.00	0.05

Notes: The Taylor rule coefficients examined are the following: $\phi_\pi = 1 : 0.05 : 5, 6, 7, 8$, $\phi_Y = 0 : 0.05 : 1, 1.5, 2, 2.5, 3, 5, 8$. R stands for the model with rational expectations and L for learning. Both models do not include additional sources of persistence, as they both perform better without them.

A.5.4 Sensitivity test for different values of σ,ϕ and ω

Table A.6: Prior distributions and posterior estimates, for the rational expectations models and models with learning, in the case where σ,ϕ and ω are alllowed to be jointly estimated.

			RES(All Mechs)		**RES(No Mechs)**		**Learn(All Mechs)**		**Learn(No Mechs)**	
Par	**Prior**	**Area**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**	**Posterior**	**Conf inter**
θ^W	$B(0.64, 0.1)$	C	0.539	$[0.388, 0.679]$	0.218	$[0.154, 0.285]$	0.614	$[0.488, 0.706]$	0.665	$[0.651, 0.678]$
		P	0.575	$[0.479, 0.665]$	0.196	$[0.123, 0.251]$	0.468	$[0.361, 0.585]$	0.565	$[0.553, 0.577]$
θ^P	$B(0.5, 0.2)$	C	0.861	$[0.839, 0.881]$	0.176	$[0.085, 0.288]$	0.211	$[0.137, 0.283]$	0.214	$[0.208, 0.22]$
		P	0.794	$[0.759, 0.822]$	0.14	$[0.03, 0.217]$	0.112	$[0.036, 0.183]$	0.038	$[0.029, 0.046]$
ϕ_π	$N(1.67, 1)$	B	3.21	$[2.722, 3.541]$	1.163	$[0.439, 2.274]$	1.927	$[1.722, 2.143]$	2.22	$[2.151, 2.323]$
ϕ_Y	$\Gamma(0.14, 0.5)$	B	1.684	$[1.068, 2.098]$	0.001	$[0, 0.008]$	1.73	$[1.567, 1.877]$	0.17	$[0.164, 0.182]$
σ	$\Gamma(2, 0.5)$	C	2.09	$[1.91, 2.363]$	2.843	$[2.037, 3.447]$	2.272	$[1.392, 3.123]$	1.603	$[1.441, 1.745]$
		P	1.68	$[1.435, 2.018]$	2.555	$[2.092, 2.957]$	2.206	$[1.174, 3.686]$	2.034	$[1.901, 2.157]$
ϕ	$\Gamma(1.5, 0.35)$	C	0.991	$[0.973, 1.023]$	4.787	$[3.698, 5.493]$	0.891	$[0.829, 0.954]$	1.243	$[1.119, 1.363]$
		P	2.302	$[2.045, 2.476]$	3.812	$[2.966, 4.793]$	1.336	$[0.819, 1.955]$	1.788	$[1.613, 1.982]$
ω	$B(0.75, 0.15)$	C	0.782	$[0.535, 0.947]$	0.887	$[0.768, 0.978]$	0.876	$[0.784, 0.98]$	0.975	$[0.966, 0.985]$
		P	0.775	$[0.441, 0.949]$	0.913	$[0.847, 0.983]$	0.628	$[0.438, 0.835]$	0.773	$[0.759, 0.787]$
η	$B(0.7, 0.1)$	C	0.554	$[0.398, 0.768]$			0.784	$[0.693, 0.87]$		
		P	0.946	$[0.909, 0.971]$			0.804	$[0.648, 0.885]$		
ρ_{CB}	$B(0.5, 0.1)$	B	0.209	$[0.099, 0.318]$			0.363	$[0.268, 0.451]$		
γ	$U(0, 1)$	C	0.669	$[0.208, 0.877]$			0.683	$[0.455, 0.991]$		
		P	0.832	$[0.246, 0.999]$			0.907	$[0.728, 0.997]$		
$\bar{g}$	$B(0.03, 0.2)$	C					0.028	$[0.004, 0.072]$	0.043	$[0.028, 0.053]$
		P					0.03	$[0.005, 0.078]$	0.014	$[0.003, 0.026]$

Notes: In the second column about the prior distributions, we use the first letter to characterize the distribution used for each parameter: U stands for uniform, G for Gamma, B for Beta. In the parenthesis of each distribution the mean and standard deviation are mentioned, except for the Uniform prior, for which lower and upper bounds are depicted. Letters C,P,B stand for Core, Periphery and Both respectively. Posterior means and 95% credible intervals have been calculated over 500,000 Metropolis-Hastings draws, discarding a burn-in of 40% draws following Milani (2017).

Table A.7: Log marginal Likelihood and posterior probabilities of each model, in the case where σ,ϕ and ω are alllowed to be jointly estimated.

	RES(All Mechs)	**RES(No Mechs)**	**Learn(All Mechs)**	**Learn(No Mechs)**
Log marg. Likelihood	-59.48	-9.00	-15.31	-2.68
	(16.32)	(2.21)	(3.64)	(0.87)
Posterior prob	0.0000	0.0018	0.0000	0.9982

Notes: The log marginal likelihoods are calculated using Geweke's Modified Harmonic Mean approximation.The standard devitation of the log marginal likelihoods are shown in parenthesis.

A.5.5 Second moment properties

In this section, we present the second moment properties in the case where we apply the methodology suggested by Eusepi and Preston (2011), to examine whether learning better captures the second moment properties in comparison to the respective models with RE, independently of the initial conditions. Furthermore, we also examine whether the standard deviation of technology is lower in the case of models with learning, compared to RE models, as indicated by the relative findings of Eusepi and Preston. Tables A.8 to A.11 present the st. deviation of output, technology, the relative volatility of key variables of the model with respect to output, the co-movement of the same variables with output and finally the persistence of each variable up to four lags.

Table A.8: Relative volatility of key variables for Core and Periphery (capital, investment, labor hours, wages and inflation) using detrended data (with HP filter). For output and technology, the standard deviation is depicted.

Relative Volatility					
CORE					
Variable	Data	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
σ_y	0.0138	0.0137	0.0136	0.0138	0.0138
σ_α	-	0.0046	0.0039	0.0039	0.0034
σ_k/σ_y	0.2413	0.7713	0.7722	0.5062	0.7097
σ_π/σ_y	0.4989	1.1891	**0.6642**	0.6629	0.6731
σ_w/σ_y	0.6526	0.8984	0.9920	0.9889	0.9439
σ_c/σ_y	0.7682	0.5006	0.5893	0.6069	0.5392
σ_i/σ_y	2.2829	3.2824	**2.8257**	2.8561	3.1783
σ_l/σ_y	0.4703	0.4383	0.3851	0.5319	0.4682
PERIPHERY					
Variable	Data	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
σ_y	0.0187	0.0189	0.0189	0.0188	0.0187
σ_α	-	0.0054	0.0051	0.0044	0.0041
σ_k/σ_y	0.4322	0.7614	0.7068	0.5186	0.7016
σ_π/σ_y	0.4439	0.9018	**0.4777**	0.4988	0.5013
σ_w/σ_y	0.8220	1.0241	0.9920	1.0628	0.9374
σ_c/σ_y	0.8521	0.6196	0.5894	0.6899	0.5354
σ_i/σ_y	3.4484	2.9546	2.9535	2.6933	3.2974
σ_l/σ_y	0.8562	0.3993	0.3902	0.4539	0.4368

Table A.9: Co-movement of key variables for Core and Periphery (capital, investment, labor hours, wages and inflation) using detrended data (with HP filter).

Co-movement with output					
Core					
Variable	DATA	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
k	0.1481	0.5124	0.5756	0.6483	0.5493
π	0.6438	0.0530	-0.1217	0.0951	-0.0084
w	-0.0154	0.9089	0.9239	0.8944	0.9077
c	0.9343	0.8483	**0.9232**	0.8967	0.9078
i	0.8966	0.9533	0.9525	0.9403	0.9662
l	0.6198	0.4053	0.1593	0.2419	0.3348
Periphery					
Variable	DATA	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
k	0.3884	0.5608	0.5377	0.6746	0.6211
π	0.3527	-0.0604	-0.1540	0.0177	-0.0694
w	0.7924	0.9227	0.9229	0.9194	0.9213
c	0.7108	0.8922	0.9197	0.9232	0.8969
i	0.7546	0.9266	0.9469	0.9153	0.9645
l	0.9426	0.0994	0.1755	0.0506	0.3671

Table A.10: Persistence of selected variables for Core (output, capital, investment, labor hours, wages and inflation) using detrended data (with HP filter), up to four lags.

Persistence (Core)						
Variable	Lag	DATA	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
y	$y_{t,t-1}$	0.8854	0.8090	0.8286	0.8209	0.8452
	$y_{t,t-2}$	0.6836	0.6966	0.7278	0.7126	0.7440
	$y_{t,t-3}$	0.4384	0.6118	0.6521	0.6287	0.6662
	$y_{t,t-4}$	0.1855	0.5425	0.5895	0.5617	0.5951
k	$k_{t,t-1}$	0.9480	0.9625	0.9624	0.9602	0.9577
	$k_{t,t-2}$	0.8532	0.9201	0.9201	0.9111	0.9106
	$k_{t,t-3}$	0.7243	0.8741	0.8747	0.8580	0.8598
	$k_{t,t-4}$	0.5710	0.8254	0.8268	0.8032	0.8060
π	$\pi_{t,t-1}$	0.8136	0.8980	0.8990	0.7776	0.7816
	$\pi_{t,t-2}$	0.5348	0.8036	0.8063	0.5915	0.5961
	$\pi_{t,t-3}$	0.2414	0.7175	0.7206	0.4494	0.4529
	$\pi_{t,t-4}$	-0.0315	0.6360	0.6387	0.3329	0.3424
w	$w_{t,t-1}$	0.8890	0.9400	**0.9449**	0.9495	0.9495
	$w_{t,t-2}$	0.7703	0.8607	0.8738	0.8773	0.8819
	$w_{t,t-3}$	0.6696	0.7784	0.7994	0.7997	0.8098
	$w_{t,t-4}$	0.5561	0.6995	0.7268	0.7229	0.7385
c	$c_{t,t-1}$	0.7991	0.9441	**0.9269**	0.9489	0.9347
	$c_{t,t-2}$	0.5754	0.8744	**0.8584**	0.8803	0.8714
	$c_{t,t-3}$	0.3173	0.8032	**0.7922**	0.8085	0.8081
	$c_{t,t-4}$	0.0868	0.7341	0.7283	0.7381	0.7448
i	$i_{t,t-1}$	0.7911	0.7185	0.7466	0.6264	0.7625
	$i_{t,t-2}$	0.6679	0.5826	0.6202	0.4693	0.6307
	$i_{t,t-3}$	0.4979	0.4936	0.5401	0.3767	0.5420
	$i_{t,t-4}$	0.2717	0.4273	0.4814	0.3195	0.4647
l	$l_{t,t-1}$	0.9237	0.4378	0.5296	0.5390	0.6495
	$l_{t,t-2}$	0.7976	0.2884	0.3531	0.4043	0.4763
	$l_{t,t-3}$	0.6395	0.2229	0.2825	0.3190	0.3759
	$l_{t,t-4}$	0.4535	0.1881	0.2506	0.2570	0.2963

Table A.11: Persistence of selected variables for Periphery (output, capital, investment, labor hours, wages and inflation) using detrended data (with HP filter), up to four lags.

Persistence (Periphery)						
Variable	Lag	DATA	RE (All Mechs)	RE (No Mechs)	LEARN (All Mechs)	LEARN (No Mechs)
y	$y_{t,t-1}$	0.9443	0.8379	0.8347	0.8531	0.8624
	$y_{t,t-2}$	0.8442	0.7339	0.7278	0.7549	0.7689
	$y_{t,t-3}$	0.7191	0.6576	0.6476	0.6820	0.6964
	$y_{t,t-4}$	0.5861	0.5917	0.5785	0.6169	0.6290
k	$k_{t,t-1}$	0.9519	0.9632	0.9619	0.9601	0.9593
	$k_{t,t-2}$	0.9090	0.9222	0.9188	0.9121	0.9150
	$k_{t,t-3}$	0.8428	0.8782	0.8721	0.8607	0.8678
	$k_{t,t-4}$	0.7773	0.8322	0.8228	0.8076	0.8182
π	$\pi_{t,t-1}$	0.8405	0.8966	0.8996	0.7748	0.7830
	$\pi_{t,t-2}$	0.5623	0.8036	0.8083	0.5913	0.5985
	$\pi_{t,t-3}$	0.2476	0.7189	0.7236	0.4534	0.4580
	$\pi_{t,t-4}$	-0.0361	0.6383	0.6431	0.3396	0.3472
w	$w_{t,t-1}$	0.9080	0.9468	0.9442	0.9541	0.9476
	$w_{t,t-2}$	0.8496	0.8767	0.8704	0.8921	0.8820
	$w_{t,t-3}$	0.7624	0.8033	0.7933	0.8255	0.8141
	$w_{t,t-4}$	0.6580	0.7308	0.7175	0.7578	0.7464
c	$c_{t,t-1}$	0.3689	0.9470	0.9267	0.9535	0.9402
	$c_{t,t-2}$	0.5648	0.8811	0.8546	0.8938	0.8796
	$c_{t,t-3}$	0.2402	0.8131	0.7852	0.8309	0.8200
	$c_{t,t-4}$	0.2305	0.7465	0.7180	0.7671	0.7598
i	$i_{t,t-1}$	0.4432	0.7191	0.7592	0.6520	0.7991
	$i_{t,t-2}$	0.7171	0.5792	0.6271	0.4855	0.6805
	$i_{t,t-3}$	0.4099	0.4988	0.5412	0.4002	0.5999
	$i_{t,t-4}$	0.4716	0.4362	0.4738	0.3373	0.5254
l	$l_{t,t-1}$	0.9716	0.5574	0.5496	0.6439	0.6517
	$l_{t,t-2}$	0.9115	0.3847	0.3682	0.4817	0.4920
	$l_{t,t-3}$	0.8285	0.3156	0.2896	0.3931	0.4097
	$l_{t,t-4}$	0.7322	0.2801	0.2477	0.3302	0.3455

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ΣΧΟΛΗ ΟΙΚΟΝΟΜΙΚΩΝ ΕΠΙΣΤΗΜΩΝ
SCHOOL OF ECONOMIC SCIENCES
ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΗΣ ΕΠΙΣΤΗΜΗΣ
DEPARTMENT OF ECONOMICS

Department of Economics
Athens University of Economics and Business

The Department is the oldest Department of Economics in Greece with a pioneering role in organising postgraduate studies in Economics since 1978. Its priority has always been to bring together highly qualified academics and top quality students. Faculty members specialize in a wide range of topics in economics, with teaching and research experience in world-class universities and publications in top academic journals.

The Department constantly strives to maintain its high level of research and teaching standards. It covers a wide range of economic studies in micro-and macroeconomic analysis, banking and finance, public and monetary economics, international and rural economics, labour economics, industrial organization and strategy, economics of the environment and natural resources, economic history and relevant quantitative tools of mathematics, statistics and econometrics.

Its undergraduate program attracts high quality students who, after successful completion of their studies, have excellent prospects for employment in the private and public sector, including areas such as business, banking, finance and advisory services. Also, graduates of the program have solid foundations in economics and related tools and are regularly admitted to top graduate programs internationally. Three specializations are offered:1. Economic Theory and Policy, 2. Business Economics and Finance and 3. International and European Economics. The postgraduate programs of the Department (M.Sc and Ph.D) are highly regarded and attract a large number of quality candidates every year.

For more information:

https://www.dept.aueb.gr/en/econ/

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