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TRABAJO FIN DE GRADO EN DOBLE GRADO INTERNACIONAL ADE Y ECONOMIA

BUSINESS CYCLE ANALYSIS IN A NEW KEYNESIAN MODEL WITH MONEY

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ABSTRACT

The objective with this paper is to examine the behaviour of economic agents responding to different shocks that shape business cycle fluctuations. A version of the New Keynesian model that incorporates money is described in this paper, including key elements such as sticky prices, monopolistic competition and transaction costs. The paper also evaluates and compares the performance of two alternative settings of a prominent monetary policy rule based on the nominal interest rate as the policy instrument. The baseline set-up uses Taylor (1993) proposed parameters, whereas the alternative model takes as a reference the parameters proposed by Smets (2002). Comparison is based on the second moment statistics extracted from the simulations of the model in MatLab. The statistics analysed are related to the volatility, procyclicality and persistence of the endogenous variables.

Key words:

Taylor-rule; New Keynesian Phillips curve; price stickiness; monopolistic competition

RESUMEN

El objetivo de este trabajo es analizar el comportamiento de los agentes económicos frente a los diferentes shocks económicos, responsables de las fluctuaciones de los ciclos económicos. Una versión del modelo Neokeynesiano con dinero es descrito en este trabajo, en ella se incluyen elementos muy característicos de esta escuela de pensamiento como son los precios rígidos, la competencia monopolística y los costes de transacción. Este ensayo también evalúa y compara el desempeño de dos escenarios diferentes de una regla de política monetaria basada en el tipo de interés nominal como instrumento. La configuración de referencia es la regla basada en los parámetros propuestos por Taylor (1993), mientras que en el modelo alternativo utilizaremos la regla basada en la propuesta de Smets (2003). La comparación está basada en estadísticos de segundo grado extraídos tras realizar simulaciones en el programa MatLab. Dichos estadísticos están asociados con la volatilidad, la correlación con el PIB y la persistencia de las variables endógenas.

Palabras clave:

Regla de Taylor; curva Neokeynesiana de Phillips; rigidez de precios; competencia monopolística.

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1 INTRODUCTION

An economic model is a simplified version of the reality, based on assumptions, which allow us to observe, understand and make prediction about economic behaviour. If the model is well designed, it can give us a better understanding of the reality and the problems that concern an economy, such as the different shocks that will be later introduce. Solow (1956) wrote that all theory depends on assumptions which are not quite true but are inevitable for theorizing.

New Keynesians model emerged in the US during the post-war period. since then, most of the economist got on the bandwagon of this school of thought, aimed by the good results that those policies have when being applied by governments between 1945 and 1970. New Keynesian ideas are seen as a mixture of Keynesian and Real Business Cycle (RBC) most successful thoughts. While in classic models', like real business cycle model (RBC), perfect competition was assumed, neo-Keynesian ones assume monopolistic competition.

Former one was characterized by flexible prices, and the difficulty to see short-run effect of monetary policies caused by the flexible prices. Firms end up having zero benefit, as the prices equal marginal costs. The reason behind this idea is that firm enter in the market if the price is greater than marginal cost, allowed by the free entry that characterized those markets.

On the other hand, in monopolistic competition firms are price-setters, which allows them to set a price which is above the marginal cost. The difference between both is called mark-up. Therefore, firms obtain profits. Another crucial characteristic of this models is the price stickiness, it refers to the fact that prices do not adjust rapidly, their changes take time. The price rigidities solve the problem previously had for explaining short-run fluctuations. In this model we will reflect this stickiness supporting Calvo (1983) proposal. In his model, the economist assumed there is a fixed probability for firms of not being able to set the optimal prices, this probability oscillates between zero and one. In a nutshell, it is a more realistic model (closer to real life market) than the perfect competition one.

Another key factor of New Keynesian models is the inclusion of the “Neoclassical microfundations”, which specify that economic decisions are the result of the maximization of intertemporal utility or profit by households and/or firms.

Radical change on the side of expectation approaching occur at the time this theory was projected. We were used to adaptative expectations in the models, where the expectations were formed by fixed coefficient lag structures. However, their lack of relationship with government policies generated inconsistency with the real expectations and the one of the models. Rational expectations came as a solution for this problem, as they are consistent with the announced policies (see Muth, 1961).

Furthermore, central bank is also included in the model, and it face the long-run trade-off between output stability and price inflation stability, which will be one of the key points in the last part of the essay.

Finally, it is worth bearing in mind that the model is dynamic. Static models are not capable to explain the behaviour of economic variables out of and toward the equilibrium, those models ignore economic growth.

2 MODEL DESCTIPTION

2.1 Households:

We will assume that the household's sector is composed by Sidrauski-type families, infinitely lived households, as done in Calvo (1983), who seek to maximize a discounted sum of (instantaneous) utilities that depend on consumption and hours worked.

They should make optimal choices for their consumption, labour supply, amount of bonds held and real money balances.

C_t denotes household´s consumption, given in bundles of differentiated goods as in Schmidt and Wieland (2012).

$$C_t = \left[\int_0^1 C_t(i)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}, where\ \sigma > 1, is\ the\ Dixit\ and\ Stigliz\ elasticity$$

n_t denotes the number of hours worked, B_{t+1} the amount of bonds for the next period and M_t measures the end-of-period money balances.

2.1.1 Objective function and budget constraint

First, we define the household preferences, commonly addressed as utility function, where t is the subindex of a variable that indicates that a variable is time-variant.

The utility function is assumed to be strictly increasing when it comes to consumption level, being the first derivative of utility with respect to consumption, positive. It is typically concave when it refers to consumption level. The latter means that at any period additional consumption increases utility but at a diminishing rate, mathematically shown by the second derivative being negative.

Whereas labour supplied affects negatively on utility, being the first derivative of utility with respect to labour supplied negative; and the utility function convex when referring to working hours. An additional hour worked decreases utility more than the previous hour worked.

We will focus on the disutility generated by working rather than on the utility generated by the leisure time in the following CRRA specification:

$$U(c_t, n_t) = \frac{{c_t}^{1-\sigma}}{1-\sigma} - \Psi_n \frac{{n_t}^{1+k}}{1+k}$$

Instead of considering current utility levels, we should consider the life-time utility, due to the infinity live characteristic of the households.

$$Et \sum_{j=0}^{\infty} \beta^j \left(\frac{{c_{t+j}}^{1-\sigma}}{1-\sigma} - \Psi_n \frac{{n_{t+j}}^{1+k}}{1+k} \right)$$

Including Et, shows that rational expectations play a role in the model. It means that household will make their decisions taking into account the information available when deciding. Making output somewhat depend on what households expect to happen, as pointed in Muth (1961). Inspired on the paper of Lucas (1976) these expectations should not be static, they ought to depend upon the nature of the policy regime place and therefore are likely to change systematically with the regime.

Bringing into the present future utility levels with the discount factor β, which shows the importance we give in the present to the utility of further periods. It can be represented as: β=1/ (1+ ρ), with ρ>0. It represents the rate of intertemporal preference, being a number between 0 and 1, meaning that we value present consumption more than future ones.

It goes against the Golden Rule applied in the Solow (1956), where individuals value consumption today and consumption tomorrow in the same way, because in that case the objective was to maximize the steady-state consumption level.

According to Ramsey, F. (1928), this household impatience makes them not reaching higher long-run consumption levels.

Sigma (σ) is the inverse intertemporal elasticity of substitution between present and future consumption, being σ >0.

Kappa is the inverse Frisch elasticity of labour supply, being k>0.

Ψ_n is a constant value, which shows the subjective importance given to labour with respect to consumption.

Another possibility of expressing the utility function would have been an equation where we include the change in consumption form the previous period, incorporating a backward-looking dynamic.

$$U(c_t, n_t) = Et \sum_{j=0}^{\infty} \beta^j \left(\frac{(c_{t+j} - hc_{t-1+j})^{1-\sigma}}{1-\sigma} - \Psi_n \frac{n_{t+j}{}^{1+k}}{1+k} \right)$$

being h the consumption habits parameter, a value between 0 and 1.

This alternative has been widely used during the last's years in the literature of New Keynesian-DSGE models. It was recommended by Smets (2003), in order to introduce the persistence of the consumption process and delayed peak responses following a monetary shock.

Households have limitations in their spending, they cannot spend more than what they earn. This is reflected in the budget constrain:

$$W_t N_t + D_t = P_t C_t + (1 + R_t)^{-1} B_{t+1} - B_t + M_t - M_{t-1} + T_t$$

In the left part of the equation, we find the income received by the households. There exists two ways of obtaining income:

- Salary obtained by working ($W_t N_t$). W_t represents the wage per hour worked.
- Dividends obtained from firms' profits (D_t). We must consider that firms owners are households. As the model is developed under monopolistic competition, firms earn money; remember that perfect consumption led to a situation where firms profit´s equal to 0.

Contrary to what we may thought at first, the inclusion of government transfers, such as unemployment benefits, does not seem to be a good idea. Since in this model, all households are identical, so transfers receive will be covered by the increase in tax paid.

In the right part of the equation, expenditures of households are represented. In this simple model, people can only spend income in three different ways:

- Consumption of goods ($P_t C_t$): People can consume baskets of goods; each basket has a price P_t. We face the additional problem, since at any point in time firms charge different prices, due to Calvo price stickiness. However, we will assume a uniform price, the price equals the geometric mean of all contract prices.
- Tax payment (T_t): Households are obliged to pay taxes to finance government expenditures. For simplicity, we will assume a lump-sum tax. As a result, all households paid the same amount of taxes, independently to the income received.
- Portfolio choices for saving: We find two types of financial assets, money (M_t) and financial bonds (B_{t+1}). People can hold money in their pockets where we assume no interest is obtained. However, full liquidity is gained. People may as well have bonds in the present, but each period they have the possibility to buy or sell them, so we will talk about net purchase of bonds. In contrast to liquid money, bonds offer the holder the possibility of earning interest every year, at the expense of present liquidity.

However, this equation was expressed in nominal terms. To express it in real terms we should divide both parts of the equation by Pt, reaching:

$$w_t n_t + d_t = c_t + (1 + r_t)^{-1} b_{t+1} - b_t + m_t - (1 + \pi_t)^{-1} m_{t-1} + \tau_t$$

2.1.2 Role of the money in the model

Money plays a crucial role in the economy, in line with its primary functions, namely as a medium of exchange, store of value, and unit of account. Therefore, it should be a cornerstone of our model. Despite the fact that there exist different options for including money in the model, all lead to similar conclusions.

On the one hand, we can include money in the utility function, affecting positively to household´s utility.

$$U(c_t, n_t) = Et \sum_{j=0}^{\infty} \beta^j \left(\frac{{c_{t+j}}^{1-\sigma}}{1-\sigma} - \Psi_n \frac{{n_{t+j}}^{1+k}}{1+k} + \Psi_m \frac{{m_{t+j}}^{1-\gamma}}{1-\gamma} \right)$$

Being gamma (γ) the elasticity of the marginal utility of money as shown in Ma and Li (2015), $\gamma > 0$.

Nevertheless, this alternative does not represent the reality, as FIAT money by itself does not increase household utility because it does not have any intrinsic value.

On the other hand, we can introduce money as a medium of exchange; a tangible asset that is generally accepted in payment for any commodity. This function of money makes us think that transaction cost as well as time spend for shopping are reduced the more money we have.

Therefore, we have another two ways of introducing money in the model, both reflect the advantage of having a medium of exchange like money when doing transactions.

There exists the alternative associated to the time needed to purchase goods. We should therefore include a new function, the shopping time function, as done in McCallum and Goodfriend (1987).

$$s_t = s(c_t, m_t)$$

Consumption has a positive effect on the shopping time. It makes sense as the more we consume, the more time we spend in the shop. Mathematically, it is represented by the partial derivative being positive, $\frac{\partial s_t}{\partial c_t} = s_{c_t} > 0$.

Holding money reduce the time needed for purchasing goods, there is no need to go to bank to ask for a credit. Represented by the partial derivative being negative, $\frac{\partial s_t}{\partial m_t} = s_{m_t} < 0$

However, for both variables the second order derivatives are negative. If we increase the cash we have, the effect of consumption on time shopping is reduced, $\frac{\partial sc_t}{\partial m_t} = s_{c_t m_t} < 0$. The same occurred, if we increase the consumption, the effect of money on time shopping is reduced, $\frac{\partial sm_t}{\partial c_t} = s_{m_t c_t} < 0$.

Time saved can be used for working or for leisure. This idea is shown in the time constraint:

$$n_t + l_t + s_t = 1$$

Which implies that total time (normalized to 1) is devoted to either labour supply, leisure time (l_t) or shopping, done in Casares (2006)

Another alternative exists, and it is based on the existence of transaction costs when purchasing goods, inspired in Casares (2007). It is the option chosen for this model.

Transaction cost functions:

$$h(c_t, m_t) = \begin{cases} 0, & if\ c_t = 0 \\ \alpha_0 + \alpha_1 c_t \left(\frac{c_t}{m_t}\right)^{\alpha_2}, & if\ c_t > 0 \end{cases}$$

Where $\alpha_0, \alpha_1\ and\ \alpha_2 > 0$.

Similar conclusions as "shopping time function" can be extracted.

Consumption has a positive effect on the transaction cost. The more we consume, the greater the credit should be, and so the cost associated to it. Mathematically, it is represented by the partial derivative being positive, $\frac{\partial h_t}{\partial c_t} = h_{c_t} = \alpha_1(1 + \alpha_2)\left(\frac{c_t}{m_t}\right)^{\alpha_2} > 0$.

Holding money reduce transaction cost associated with the purchase of goods, because interests of a possible debt are not paid. Money allows us to get rid of an intermediary like a bank. Represented by the partial derivative being negative, $\frac{\partial h_t}{\partial m_t} = h_{m_t} = -\alpha_1 \alpha_2 \left(\frac{c_t}{m_t}\right)^{1+\alpha_2} < 0$.

For both variables the second order derivatives are negative, $\frac{\partial h_{c_t}}{\partial m_t} < 0$ and $\frac{\partial h_{m_t}}{\partial c_t} < 0$.

We will face the inclusion of the transaction costs in the budget constraint.

$$w_t n_t + d_t = c_t + (1 - r_t)^{-1} b_{t+1} - b_t + m_t - (1 + \pi_t)^{-1} m_{t-1} + \tau_t + h_t$$

2.1.3 Model/Final equations:

Now that we have both, the utility function, and the budget constraint, we can proceed with the maximization problem, that at the end is the objective of households, maximize their utility.

$$\max_{c_t, n_t, b_{t+1}, m_t} Et \sum_{j=0}^{\infty} \beta^j \left(\frac{{c_{t+j}}^{1-\sigma}}{1-\sigma} - \Psi_n \frac{{n_{t+j}}^{1+k}}{1+k} \right)$$

$$s.t.\ w_t n_t + d_t - c_t - (1 + r_t)^{-1} b_{t+1} + b_t - m_t + (1 + \pi_t)^{-1} m_{t-1} - \tau_t - h(c_t, m_t) = 0$$

For solving the problem, we use the Lagrange function. It is obtained by adding to the utility function, the multiplication of the Lagrange multiplier (λ) by the budget constraint.

$$\mathcal{L}_t = Et\sum_{j=0}^{\infty}\beta^j\left(\frac{c_{t+j}{}^{1-\sigma}}{1-\sigma} - \Psi_n\frac{n_{t+j}{}^{1+k}}{1+k}\right)$$

$$+ \lambda_t(w_t n_t + d_t - c_t - (1+r_t)^{-1}b_{t+1} + b_t - m_t + (1+\pi_t)^{-1}m_{t-1} - \tau_t - h_t)$$

$$+ \beta E_t\lambda_{t+1}(w_{t+1}n_{t+1} + d_{t+1} - c_{t+1} - (1+r_{t+1})^{-1}b_{t+2} + b_{t+1} - m_{t+1} + (1+\pi_{t+1})^{-1}m_t - \tau_{t+1} - h_{t+1})\ldots$$

First order condition with respect to consumption, lead to the definition of the Lagrange multiplier:

$$\lambda_t = \frac{c_t{}^{-\sigma}}{1+h_{c_t}},$$

It represents the shadow value of one unit of income from the budget constraint.

When realizing the first order condition for the variable working hours, we get:

$$\frac{c_t{}^{-\sigma}}{1+h_{c_t}}w_t = \Psi_n n_t{}^k,$$

The equation shows that the increase of utility provided after working and not working is equal, if they are not, we can increase our utility by either working more or less.

If people work, they will receive a wage W, which will allow them to buy bundles of good, concretely w_t ($w_t = \frac{W_t}{P_t}$, P_t is the price of one bundle). Each bundle consume provides an increase in their utility of $\frac{c_t{}^{-\sigma}}{1+hc_t}$. Right side of the equation shows the increase in utility after not working n_t hours, for that the parameter Ψ_n is crucial, because it allow us to compare the utility generated by not working and the one generated by consuming (left part of the equation). Using the equation above, we can solve for labour supply, getting:

$$n_t = \left(\frac{w_t c_t{}^{-\sigma}}{\Psi_n(1+h_{c_t})}\right)^{\frac{1}{k}}$$

The Euler equation is obtained from combining the first order conditions of bonds with the value of the Lagrange multiplier implied by the consumption first order condition:

$$\frac{c_t{}^{-\sigma}}{(1+h_{c_t})(1+r_t)} = \beta E_t\left(\frac{c_{t+1}{}^{-\sigma}}{1+h_{c_{t+1}}}\right)$$

This equation explains how we decide between present and future consumption, the utility that both give should be equal.

Left-hand side show the net gain of utility if we increase current consumption in one unit. Household´s utility increase in $\frac{c_t^{-\sigma}}{1+hc_t}$, we should also include the opportunity cost of consumption $(1 + r_t)$, net gains that would be obtained if money devote for consumption is used for other purposes, like bonds, which give us interests.

Right-hand side of the equation show the net gain of utility we increase future consumption in one unit. Important to note that future consumption does not have opportunity cost.

Prior to do the last first derivative, we need to first introduce the Fisher equation, which connects the nominal interest rate and inflation rate to have the ex-ante real return of bonds:

$$1 + r_t = \frac{1 + R_t}{1 + E_t\pi_{t+1}}$$

Inflation rate equation would also be important, it represents the change in prices from one period to another:

$$\pi_t = \frac{P_t}{P_{t-1}} - 1$$

Finally, if performing the first order condition of money, and making use of Euler equation and Fisher equation, we end up having the money demand function:

$$m_t = c_t \left[\frac{a_1 a_2}{R_t/1 + R_t}\right]^{\left(\frac{1}{1+a_2}\right)}$$

Important to highlight that more money is demanded when consumption increase. In spite of what we may think, for buying more units, we need more money; the real reason resides in the idea that increasing the consumption will be traduced in a lower opportunity cost of holding money. Money demand is increased if interest rate goes down, reflecting the idea of the opportunity cost and the substitution between money and bond holdings in the portfolio choice.

However, all those equations need to be log-linearized to have linear equations, compulsory requirement for solving the model. Log linearizing the labour supply curve we end up having:

$$\hat{n}_t = \frac{1}{\kappa}\left(\widehat{w}_t - \sigma\hat{c}_t - h_c\widehat{h_{c_t}}\right)$$

Same process for the Euler equation led to:

$$\hat{c}_t = E_t\hat{c}_{t+1} - \frac{1}{\sigma}(r_t - r) - \frac{hc}{\sigma}\left(\widehat{h_{c_t}} - E_t\widehat{h_{c_{t+1}}}\right)$$

Finally, for the money demand, log-linearization lead us to reach:

$$\widehat{m}_t = \hat{c}_t - \frac{1}{(1+a_2)R}(R_t - R)$$

We should include here equations referring to the transaction cost, which appear in the equations above:

$$\widehat{h_{c_t}} = a_2(\hat{c}_t - \widehat{m}_t)$$

Hat variables, like $\hat{n}_t$, represents deviations from steady state, always respect to 1. Aforementioned state take place in a scenario where variables are not affected by shocks, therefore it is invariant. Hat variables are obtained after subtracting log variables with the subindex and the same variable without subindex. We assume an important approximation:

$$\log x_t - \log x \approx \frac{x_t - x}{x}$$

In this model we are interested in the business cycles, so the upper formula allows us to see how the current situation (x_t) is with respect to the long-run equilibrium also called steady-state (x). For obtaining the long-run equilibrium we should perform the model with only deterministic variables (no shocks neither future expectation)

2.2 Firms:

Production of goods resides in charge of the firms, who demand labour to produce consumption goods attending customers' demands. We have seen that households supply labour, having the double role of customers and workers.

As mentioned in the introduction, the model takes place in a monopolistic competition, following the seminar paper by Dixit and Stiglitz (1977) proposition. Therefore, firms are responsible for the price setting and seek to maximize profits. They receive revenues for the units sold, facing by the Dixit and Stiglitz demand constraint:

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} y_t$$

Where $y_t(i)$ shows firm i aggregate demand, which depends on the relative price of their product with respect to the market one. Zeta (θ) is the elasticity of substitution across goods, indicating how much should production decrease when relative price increase. It should be greater than 1, explaining that the greater the relative price is, the lower the demand for the firm´s product will be, as cheaper option would be easily found.

Zeta will also allow us to obtain the markup of the selling price over the marginal cost of production, which will be later used:

$$Markup = \left(\frac{\theta}{\theta - 1} - 1\right) * 100$$

When referring to the price, it is worth bearing in mind that the model assumes sticky prices, as introduced by Calvo (1983). Sticky prices are characterized by the fact that individual prices are not subject to continuous revisions, as well as by the assumption that the price revisions are not synchronous, in order words, they occur randomly. Each period all companies have the same probability of changing the price, it is not backward-looking in this sense.

This price stickiness can be reflected in two different ways, but we will focus on Calvo proposal. Leaving out of the menu costs approach introduced by Sheshinski and Weiss (1977), who argued that firm would not rise continually the price, because a price rise influences firms cost so it must be justified by an overall increase in revenue of the company. In the paper they explain the example of a restaurant, where the menus should be changes when there is a change in prices. If the total cost of printing new menus is greater than the benefits obtained by increasing the prices, the change of prices should not take place.

On his proposal, Calvo (1983) suggested that enterprises cannot change their products prices whenever they want. At period t, only a percentage of 1-η firms, have the chance to change their price, η is a value between 0 and 1. Therefore, aggregate price level is explained as:

$$P_t = \left[(1-\eta)P_t(i)^{1-\theta} + \eta[(1+\pi+Z_t)P_{t-1}]^{1-\theta}\right]^{\frac{1}{1-\theta}}$$

Aggregate price is the sum of the prices of all firms. Even though some firms are not allowed to change their prices, only allowed to adjust their previous price (P_{t-1}) with the inflation rate subject to inflation shock (Z_t), this adjustment is called indexation. Others do change their prices setting them at the optimal price level, being $P_t(i)$ for firm i. Previous equation takes as reference the Dixit and Stiglitz (1977) price equation:

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta} di\right]^{\frac{1}{1-\theta}}$$

In the aggregate price level equation, it appears an inflation shock which follows an autoregressive correlation, AR (1):

$$Z_t = \varphi_Z Z_{t-1} + \varepsilon^{Z_t} \quad where\ \varphi_t < 1\ and\ \varepsilon^{Z_t} \sim N(0, \sigma_{Z_t}^2)$$

Companies' objective is to maximize profits, according to neoclassical microfundations. As occurred with the households, enterprises are not just focused on present objective, but also future ones. Firm profits are represented by the following equation:

$$E_t \sum_{j=0}^{\infty} \beta^j \eta^j \left(\frac{\Pi_{t,t+j}^p P_t(i)}{P_{t+j}} y_{t+j}(i) - w_{t+j} n_{t+j}(i)\right)$$

Businesses obtain money by selling goods in the market. Their sales are given by their demand, so if the aggregate demand of company´s product is $y_{t+j}(i)$.Apart from that, companies also have costs, in this model we will just include the variable cost of salaries paid to workers.

Operator $\Pi_{t,t+j}^p$, represents the accumulation of the price indexation factor of all periods between *t* and *t+j*, as follows:

$$\Pi_{t,t+j}^p = \prod_{t=1}^{j} (1 + \pi + Z_t)$$

We face the following maximization problem:

$$\max_{p_t(i)} E_t \sum_{j=0}^{\infty} \beta^j \eta^j \left(\frac{\Pi_{t,t+j}^p P_t(i)}{P_{t+j}} y_{t+j}(i) - w_{t+j} n_{t+j}(i)\right)$$

$$s.t.\ y_{t+j}(i) = \left(\frac{\Pi_{t,t+j}^p P_t(i)}{P_{t+j}}\right)^{-\theta} y_{t+j}, for\ j = 0,1\ldots$$

Where we end up obtain the next profit goal equation:

$$\max_{p_t(i)} E_t \sum_{j=0}^{\infty} \beta^j \eta^j \left(\left(\frac{\Pi_{t,t+j}^{p} P_t(i)}{P_{t+j}} \right)^{1-\theta} y_{t+j} - w_{t+j} n_{t+j}(i) \right)$$

If solving using first order equations:

$$\frac{\partial Profit}{\partial P_t(i)} = E_t \sum_{j=0}^{\infty} \beta^j \eta^j \left[(1-\theta) \left(\frac{\Pi_{t,t+j}^{p} P_t(i)}{P_{t+j}} \right)^{-\theta} \frac{\Pi_{t,t+j}^{p}}{P_{t+j}} y_{t+j} - w_t \frac{\partial n_t(i)}{\partial y_t(i)} \frac{\partial y_t(i)}{\partial P_t(i)} \right]$$

We get the interesting correlation within working hours and price level. There is an indirect connection, with production level acting as the glue within both.

Price level relation with production level, is already shown in the demand constrain, being $\frac{\partial y_t(i)}{\partial P_t(i)} < 0$. Whereas connection between working hours and production level has not yet been introduced. For doing so, we should explain the production equation:

$$y_t(i) = \varepsilon^{\omega_t} n_t(i) \; where \; \omega_t = \varphi_\omega \omega_{t-1} + \varepsilon^{\omega_t}$$

In more complex models, a Cobb-Douglas production function tend to be used, where the output level is affected by capital level and labour level, like Casares (2017). This model will just include the effect of the latter. For simplicity reasons we assume no capital accumulation, as well we will ignore the idea of decreasing labour productivity. In this model, workers will contribute the same the first hour of work than the second, which is a principle that does not occur in real life.

Therefore, production will be affected by labour and by an exogenous technology shock (ω_t), who is represented by an AR (1) process. Greater technology shock implies that if ceteris paribus (same level of labour) greater production will be obtained. It does make sense as workers will become more productive if innovations are adopted by the enterprise.

We can simplify first order equation obtained above if we include the marginal productivity of labour (MPL). It reflects the increase in production when labour is increased in one unit, when the employee works one more hour. Mathematically, explained by the following equation:

$$f_{n_t(i)} = \frac{\partial y_t(i)}{\partial n_t(i)} = \varepsilon^{\omega_t}$$

Moreover, marginal cost can be included in the equation. It has direct relation with wage and marginal productivity of labour:

$$w_t = mc_t(i) f_{n_t(i)}$$

$mc_t(i)$ represents the increase in cost if production is increased in one unit. Therefore, right-hand side of the equation above shows how much would cost increase if labour were increased in one unit, which coincides with the definition of salary, w_t.

If we continue operating with the first order derivative, we end up having:

$$P_t(i) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{j=0}^{\infty} \beta^j \eta^j mc_{t+j} P_{t+j}{}^{\theta} \Pi_{t,t+j}^{p}{}^{-\theta} y_{t+j}}{E_t \sum_{j=0}^{\infty} \beta^j \eta^j P_{t+j}{}^{\theta-1} \Pi_{t,t+j}^{p}{}^{1-\theta} y_{t+j}}$$

If we were in a situation of flexible prices, $\eta = 0$, so that prices are adjusted every period:

$$P_t(i) = \frac{\theta}{\theta - 1} mc_{t+j} (\text{SI incluyes en la dixit aquí habría q dividir entre } \Pi)$$

Knowing that the markup ($\frac{\theta}{\theta-1}$) is greater than 1, price will always be higher than marginal cost. Demonstrating that firms earn profits per unit sold.

Log-linearizing the optimal price equation led us to reach:

$$\hat{P}_t(i) = (1 - \beta\eta) \sum_{j=0}^{\infty} \beta^j \eta^j E_t\left(\widehat{mc}_{t+j} + \hat{P}_{t+j}\right)$$

By the properties of the logarithm, nominal marginal cost is obtained from the sum of real marginal cost and $\hat{P}_{t+j}$. Optimal price equation (non-linearize one) shows that price would increase if marginal cost (either nominal or real) increase. Nonetheless, not only present marginal cost is considered, but also future ones. The reason behind this idea is the assumption that firms cannot change their price whenever they desire. This uncertainty makes firms try to predict future costs. The greater the probability of not being able to change prices, the greater importance given to future marginal cost.

Now that we have the optimal price equation, it is time to connect it with inflation. First, we need to log-linearize price aggregate and inflation equations. Obtaining:

$$\hat{P}_t = (1 - \eta)\hat{P}_t(i) + \eta(1 + \pi)\hat{P}_{t-1} + \eta(1 + \pi)Z_t$$

$$\pi_t - \pi = \hat{P}_t - \hat{P}_{t-1}$$

Combining both led us to the next result:

$$\pi_t - \pi = \frac{1-\eta}{\eta}\left(\hat{P}_t(i) - \hat{P}_{t-1}\right) + \frac{1}{\eta} Z_t$$

It determines that inflation proportionally occurs when optimal prices are above aggregate prices.

With the previous equation and the log -linearize optimal price equation, we get the New Keynesian Phillips Curve:

$$\pi_t - \pi = \beta E_t(\pi_{t+1} - \pi) + \frac{(1-\beta\eta)(1-\eta)}{\eta}\widehat{mc}_t + (1-\beta\varphi_Z)Z_t$$

Being φ_Z the coefficient of autocorrelation of the AR(1) inflation shock.

Phillips's curve represents inflation dynamics. It argues that inflation rate depends positively on the marginal cost. It makes sense, because as seen in optimal price equation marginal cost also affects positively on price level, which as show in the equation explained before is correlated with the inflation by a positive sign. It goes without saying, that expectations about future inflation affects current inflation levels. Inflation shock also plays an important role in the equation, if a shock occur current inflation will rise. the persistence of the shock will be given by the parameter φ_Z, the greater the persistence, mean the greater the shock will last, and the lower the effect will be on current inflation.

Up to the moment, the number of variables exceed the number of equations. Therefore, for solving the model, we need more equations.

Marginal cost can be one that can be log linearized, leading to:

$$\widehat{mc}_t = \widehat{w}_t - \omega_t$$

Moreover, log-linearization can also be applied to production function, reaching:

$$\hat{y}_t = \omega_t + \hat{n}_t$$

Doing the log-linearization for Fisher equation we reach:

$$r_t - r = (R_t - R) - E_t(\pi_{t+1} - \pi)$$

Interest rate and inflation rate as are expressed in rate do not need to be expressed by the hat.

2.3 Government and central bank

Public sector is a cornerstone of our economy, being one of the main creators of business cycles. However, its role in this model would be limited. We will include a government that can purchase goods in the market. One of the main assumptions regarding government, is that each period it has a budget constraint, with three sources of funding.

Reason for including the government resides in the fact that if families save money holding bonds, others should spend that money that is saved, in this case, the government.

Government also has a budget constraint:

$$g\varepsilon^{g_t} = \tau_t + (1 + r_t)^{-1} b_{t+1} - b_t + m_t - (1 + \pi_t)^{-1} m_{t-1}$$

Left part of the equation shows that government spending is affect by a shock, called government spending shock g_t, explained by an AR (1):

$$g_t = \varphi_g g_{t-1} + \varepsilon^{g_t} \; where \; \varepsilon^{g_t} \sim N\left(0, \sigma_{g_t}^2\right)$$

Right-hand side of the equation explains financial sources for the government. One possibility is to raise taxes (τ_t), if is the alternative chosen, citizens pay through taxes the public spending. In this model taxes are lump sum, so they do not depend on the income of the household. Another possibility is to get money by issuing bonds ($(1 + r_t)^{-1} b_{t+1} - b_t$), promising buyers to give back the money plus some interests. It is an interesting option as both parts win, government obtain liquidity and households will earn an interest in the future. Finally, government can obtain financing by printing money ($m_t - (1 + \pi_t)^{-1} m_{t-1}$).

Adding the households budget constraint we get the overall resource constraint, which is the goods market clearing condition:

$$y_t = c_t + g\varepsilon^{g_t} + h_t$$

It claims that everything that is produced is demanded. Log-linearizing this equation led to:

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{g}{y}\hat{g}_t + \frac{h}{y}\hat{h}_t$$

As done with the households' equations, we should include the transaction cost equation that appear in the equation before:

$$\hat{h}_t = \frac{h - a_0}{h}[(1 + a_2)\hat{c}_t - a_2\widehat{m}_t]$$

Moreover, a central bank also appears in our model. It is an independent institution that provide financial and banking service. Many authors criticise the independency of the central bank, arguing that central banks have a connection with the national governments.

It has the competence of the monetary policy, therefore responsible of stimulating or depressing the economy of its country. Four different instruments can be used by the central banks for goading the economy as explained by the European Central Bank (2022), they are open-market operations, standing facilities, minimum reserve requirements and forward guidance, which affect expectations of households and firms. The latter is affected by the credibility of the institution, it implies that central bank press declarations will only have a true effect if population and firms' expectation If the agents trust the institution.

However, the most important instrument is the money supply, if it is increased, we are facing an expansionary policy, whereas if money supply is decreased, we observe a contractionary policy.

As argued above, central bank is responsible of the monetary policy, deciding according to the interest rate, with the objectives of stabilizing inflation, as well as the GDP, while at the same time have a financial stability (low volatility of the interest rate)

Monetary policy is shown below by the Taylor rule proposed by John Taylor (1993), which explains the responses of the nominal interest rate:

$$R_t - R = \mu_R(R_{t-1} - R) + (1 - \mu_R)\left[\mu_\pi(\pi_t - \pi) + \mu_y(\widehat{y}_t)\right] + \chi_t$$

$$where\ 0 < \mu_R < 1, \mu_\pi > 1, \mu_y > 0$$

Monetary policy shock is a white noise process:

$$\chi_t = \varepsilon^{\chi_t}$$

μ_R represent the smoothing coefficient, if its value is very high the central bank is very worried about the financial stability so interest rate would be highly affected by the lagged interest rate, so interest rate moves are going to be done in a sequence of small steps. $\mu_y$and μ_π are associated to macroeconomic stabilization, stabilization of the production and stabilization of inflation respectively. Being $\mu_\pi > 1$, explains that if inflation rise so should interest rates. While being $\mu_y > 0$, explains that if GDP rise above the potential output (y, which represents the efficient level of production of an economy) so should interest rates, fostering a contractionary policy, as will decrease investment, that will allow us to stay closer to the steady state, explained by Smets (2003).

In consequence, interest rate will rise (go down), if previous period interest rate in above (below) the steady-state, if inflation rate is above (below) the steady-state, if output is above (below) the steady-state.

Taylor rule proved its efficiency during the period of 1987-1992 in the US, in this time the interest rate suggested by the rule is very close to the rate that was chosen, as expressed in Taylor (1993)

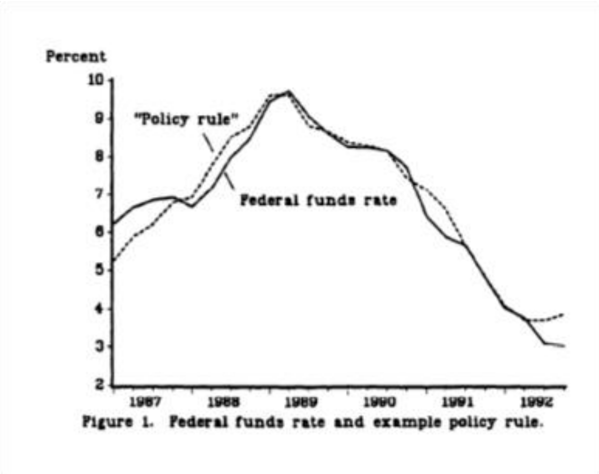

Figure 1. Federal funds rate and example policy rule. Obtained from: Taylor (1993)

2.4 Model equations and variables

Gathering the information explained above, the model has 12 equations and 12 endogenous variables. For solving the model, number of equations and number of variables should coincide.

Endogenous variables are those whose value are determined by other variables values. This model has 12 endogenous variables, $\hat{c}_t, \hat{n}_t, \widehat{m}_t, \widehat{w}_t, r_t - r$, $R_t - R, \pi_t - \pi, \widehat{mc}_t, \hat{y}_t, \widehat{hc}_t, \hat{h}_t$ and $\widehat{\not{f}_{n_t(\iota)}}$

Exogenous variables are variables that cannot be controlled but have an effect in other variables value. In the model we have: $g_t(government\ spending\ shock), \chi_t(monetary\ policy\ shock), Z_t(inflation\ shock), \omega_t$ $(technology\ shock)$

Predetermined variables are the variables that we already know their value when making policy decisions, in this model we just have $R_{t-1} - R$.

Exogenous and predetermined variables are also called state variables, they are the information we have when deciding.

Equations of the model are:

$$(1)\ \hat{n}_t = \frac{1}{\kappa}\left(\widehat{w}_t - \sigma\hat{c}_t - h_c\widehat{h_{c_t}}\right)$$

$$(2)\ \hat{c}_t = E_t\hat{c}_{t+1} - \frac{1}{\sigma}(r_t - r) - \frac{hc}{\sigma}\left(\widehat{h_{c_t}} - E_t\widehat{h_{c_{t+1}}}\right)$$

$$(3)\ \widehat{m}_t = \hat{c}_t - \frac{1}{(1+a_2)R}(R_t - R)$$

$$(4)\widehat{h_{c_t}} = a_2(\hat{c}_t - \widehat{m}_t)$$

$$(5)\ \pi_t - \pi = \beta E_t(\pi_{t+1} - \pi) + \frac{(1-\beta\eta)(1-\eta)}{\eta}\widehat{mc}_t + (1 - \beta\varphi_Z)Z_t$$

$$(6)\ \widehat{mc}_t = \widehat{w}_t - \omega_t$$

$$(7)\ \hat{y}_t = \omega_t + \hat{n}_t$$

$$(8)\ r_t - r = (R_t - R) - E_t(\pi_{t+1} - \pi)$$

$$(9)\ R_t - R = \mu_R(R_{t-1} - R) + (1 - \mu_R)\left[\mu_\pi(\pi_t - \pi) + \mu_y\widehat{y_t}\right] + \chi_t$$

$$(10)\ \widehat{f_{n_t(\iota)}} = \omega_t$$

$$(11)\ \hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{g}{y}\hat{g}_t + \frac{h}{y}\hat{h}_t$$

$$(12)\hat{h}_t = \frac{h - a_0}{h}\left[(1+a_2)\hat{c}_t - a_2\widehat{m}_t\right]$$

With the following shocks:

$$\omega_t = \varphi_\omega\omega_{t-1} + \varepsilon^{\omega_t}$$

$$Z_t = \varphi_Z Z_{t-1} + \varepsilon^{Z_t}$$

$$g_t = \varphi_g g_{t-1} + \varepsilon^{g_t}$$

$$\chi_t = \varepsilon^{\chi_t}$$

3 CALIBRATION

This section describes the calibration of the model parameters. It consists of the process of giving values to the parameters of the model to make it reflect the reality. However, instead of conducting a Bayesian estimation we will make use of a calibration that is widely accepted by the economist world. For doing so, we will inspire on papers of different authors.

Following the same order as in the model, households' parameters will be the first topic. Labour supply equation include parameters kappa (κ), which is the inverse of Frisch labour supply elasticity, and sigma (σ), which shows the inverse intertemporal elasticity of substitution. The former will take value κ=2 inspired in the research of Card (1994) and Altonji (1986), whereas the latter value is σ=1.39 as estimated by Smets and Wouters (2007). Discount factor (β) takes value 0.995 as ρ is assumed to be 0.005 (0.5% per quarter, 2 per year).

When it comes to the calibration of the transaction cost equation, we will assume a_2=4, which explains the curvature of transaction cost function; $\frac{h-a_0}{h}$ represents the variable part of the transaction cost and has a value of 0.5; hc is assumed to be equal to 0.05, it represents the marginal transaction cost. Lastly, $\frac{h}{y}$=0.01 showing that the transaction cost represents a very small part of economy output.

Secondly, firm's parameters are the next objective. Starting with Calvo probability of price stickiness (η), we will take into account the paper of Erceg, Henderson and Levin (2000) by which η=0.75. For this reason, firms would set optimal prices once every four periods, as we take a quarter as the reference period, firms can set optimal prices one time per year. Elasticity of substitution across goods, is represented by the variable zeta (θ), whose value is based on the idea of having a markup of 20%, as a result θ=6.

Regarding the shocks, the parameter that is defined is the autocorrelation (φ) of the shock. For all those parameters ($\varphi_\omega, \varphi_Z, \varphi_g$), the article of reference is Clarida, Gali and Gertler, M. (2000). The autocorrelation of the technology shock is $\varphi_\omega = 0.95$, for the inflation shock is $\varphi_Z = 0.85$, while for the government spending shock is $\varphi_g = 0.8$.

Finally, parameters regarding government and central bank would be analysed. Wide range of parameters were introduced in the Taylor Rule, for those we will follow the ideas presented by Taylor (1993) because they seem to lead to interests like those of the reality.

Ergo μ_{π}=1,5, it implies that interest rate will increase in 1.5% per each unit of increase in inflation rate; μ_{y}=0,5/4, implying that interest rate will increase 0.125% when the output increase in one unit; μ_{R}=0,79, which is the smoothing interest rate.

Nominal interest rate in steady state is R=(5/400) %.

The share of government spending with respect to GDP ($\frac{g}{y}$) is 0.3, and the share of consumer spending ($\frac{c}{y}$) is 0.69. Hence, 30% of the GDP is spend by the government and 69% is spend by the customers, the rest, 1% is spend in transaction cost

4 IMPULSE RESPONSE FUNCTIONS

This section will focus on the impulse response functions. They attempt to explain the evolution of the most important endogenous variables when the model faces an external shock. As previously seen, this model includes four different shocks, the technology shock (ω_t), the inflation shock (Z_t), the government spending shock (g_t) and the monetary policy shock (χ_t), which conform the exogenous variables. Those variables play a crucial role in the model because they are the only way of including variability in the model.

The objective is not only to analyse the short-run effect of the exogenous shocks on the endogenous variables, but also the long-run effect, focusing on the return of the endogenous variables to their steady state.

Previously we have showed the definitions of the shocks (Section 2.4). However, it is now time to explain it deeper.

One the one hand, ω_t, Z_t, g_t are represented by an autoregressive process, concretely, by an AR(1) process. It means that the value of the shock depends on the value of the shock during the last period. Parameter Fi (φ) give us information of this persistence. The shock would have greater inertia when the value of the parameter is high. Undoubtedly, the shock with greater persistence is the technology one.

On the other hand, the monetary shock is the only one that does not have persistence in the equation, previous years shock value does not affect present one, making impossible the anticipation to it. Therefore, this shock can be explained as a white noise process.

Nonetheless, the Taylor rule included in the model argues that interest rate depends positively on last period interest rate, so the persistence of the monetary shock is included by this equation.

It is important to introduce the standard deviation of the error, which represents the volatility of the shock. Consequently, if the standard deviation is low, shock values tend to have values is a short range of values.

For solving the model, we will make use of MATLAB, which is a numeric computation software used for analysing data, developing algorithms, or solving models. One of the main characteristics is that it has its own programming language. Concretely, we will make use of Paul Klain file, as done in McCallum (1998), because the file allows to solve linear models with rational expectations. The file uses matrixes (M1,M2,M3 and M4) in order to solve the model, following this solution form:

$$x_t = M1 * k_t + M2 * u_t$$

$$k_{t+1} = M3 * k_t + M4 * u_t$$

M1 shows the coefficient of reaction of endogenous variables (x_t) to the predetermined variables (k_t). Only one predetermined variable appears in the model, so M1 would be a column matrix. It has 12 rows, coinciding with the number of endogenous variables.

M2 shows the coefficient of reaction of endogenous variables to the four different shocks (u_t). It has 12 rows and 4 columns, as there exists 4 shocks.

For example, doing for the output level: y_t=-1.524*R_{t-1}+0.47*ω_t+0.2*g_t-1.93*χ_t-0.23*Z_t. We see that previous year interest rate, a monetary shock and an inflation shock has a negative effect on the output level. Whereas the government and technology shock have a positive impact on output levels.

M3 shows the coefficient of reaction of next period exogenous variable to the predetermined variables (k_t). It only has 1 row and 1 column.

M4 shows the coefficient of reaction of next period exogenous variable to the four different shocks (u_t). It has 1 row and 4 columns as there are 4 shocks.

Numerically, we obtain: R_t=0.46*R_{t-1}-0.12*ω_t+0.02*g_t+0.63*χ_t+0.07*Z_t

As occurred with the previous equation, the most important information given are the signs.

For explaining the impulse response functions, we should distinguish the shock that provokes the movement in the endogenous variable's values.

4.1 Technology shock

The first impulse response function that would be analyse refers to the technology shock. Due to its highly correlation with production, it is also called production technology shock.

When referring to it our mind should instantaneously think on innovation, as it reflects the improvement in firm´s technology.

As it has greater autocorrelation parameter, its effect will last longer than for other shocks.

Putting ourselves in a situation, we will associate this shock to the introduction of computers to firms during their beginnings. The period of introduction is quarter 1, and its immediate consequence is associated to workers productivity and hence in company's overall production.

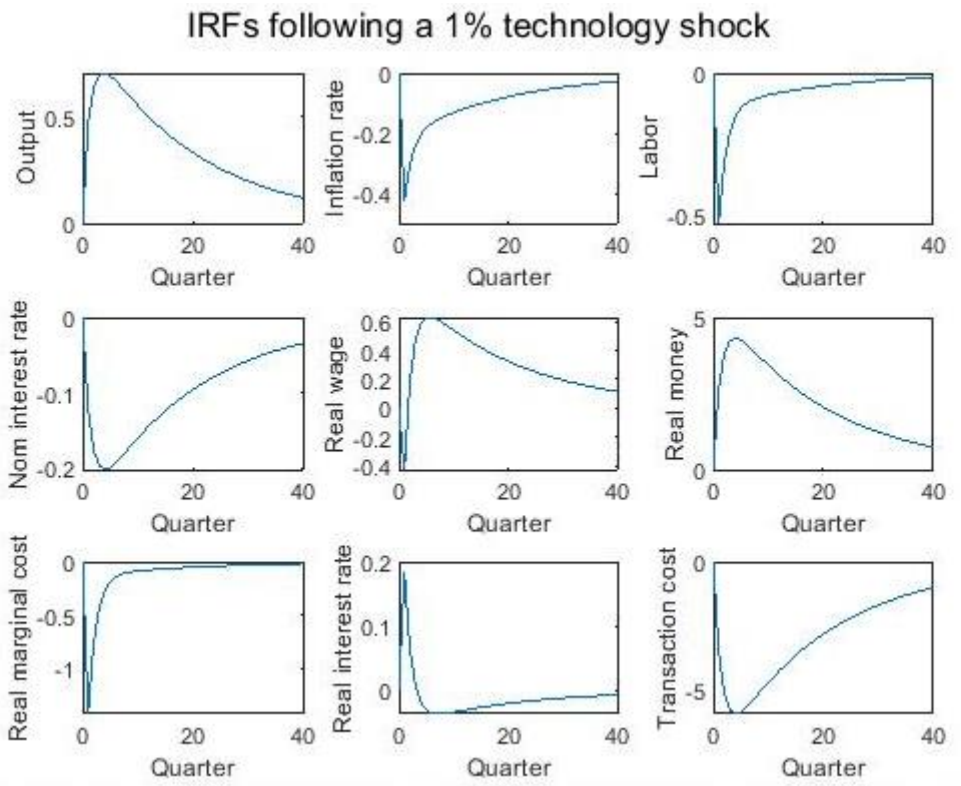

Figure 2. Technology shock. Obtained from MatLab

Initially, productivity of employees rises, with the same level of input the output of the firm push up. Therefore, company production will growth sharply. Increase in the economy GDP, is translated in an increase of consumption levels and/or government spending according to the overall resource equation.

Due to the increase in productivity the initial reaction is to decrease company´s workforce, rising the unemployment rate. Alternatively, firms can reduce the hours worked by each worker. The reason behind is the idea explained above, with less labour input, firms can produce the same level of output. For having less workforce, the company should decrease the wage paid, disincentivizing employees to continue working. Part of the workforce would stop working due to the decrease in wages.

The initial decrease of wages sum to the rise in productivity, will lead to a huge decrease of the real marginal cost. Variables cost that are represented by the wage paid to the employees, have decrease. As a result, for producing one unit of product, firm´s cost decrease.

Due to the fact that marginal costs have decreased, prices will go down. Firms are part of a competitive market, where they make use of the price in order to gain customer attention. Consequently, if the marginal cost goes down, so will do the price of the product. An overall decrease in prices in an economy results in a period of deflation, which is what happened in the first quarters. Current inflation affects agent´s inflation expectations about the future, deflationary periods are translated in an expectation of future deflation periods.

Despite the increase in overall production, interest rates go down, which according to the Taylor rule seem to have no-sense. The reason of the decrease of interest rates resides in the fact that inflation levels have decreased, and it has a greater relevance in the interest rates values because the parameter value μ_{π}=1,5 is greater than μ_{y}=0,5/4.

In spite of the decrease of the nominal interest rate, real interest rate rises. The effect of the nominal interest rate is overweighted by agent´s expectation of inflation, they expect deflation to continue in the future.

The decrease of real interest rate disincentivize money holding because the opportunity cost is reduced. Remind that the opportunity cost of money holding is the interest gained by holding bonds, if the interest paid are decreased more people will prefer the liquidity gained by keeping money. Moreover, money balances are increased due to the increase in consumption levels.

When it comes to the transaction cost, movements of real money balance and consumption levels affect the variable in opposite directions. While the increase in consumption levels makes transaction cost to increase, the increase in money holdings decrease transaction cost. Because the increase in money holding is greater than the one of consumption levels, the transaction costs will be reduced.

However, the effect from that productivity decreases within the periods. Decrease of productivity will make the opposite effect of what was showed above, the output start to decrease and marginal cost start to rise again**.**

Moreover, workers have realized that during that period their productivity have rose, that by working the same they produce more, so they will ask for a grater salary. It would be conceded as now more labour is demanded by firms due to the decrease in productivity. Company´s increase profits entitle workers to be part of this good situation of the firm, as they conform part of the stakeholders.

Inflation will start to rise because prices rise due to the increase in marginal cost. This has an implication on the nominal interest rate, which will increase. The inflation expectations create an immediate effect on the real interest rate, which decreases.

Real money holding start to decrease when the output level does, seeing that the effect of the real interest rate is quite low, mainly as it has change very little.

To sum up, once the shock starts to disappear, the economy goes back to equilibrium.

4.2 Government spending shock

Secondly, we will analyse the impulse response functions associated with the government spending shock. In this case, the distortion from steady state will start by the 1% increase in government spending, which is a fiscal expansionary policy. Government spending can be used for increasing pensions, unemployment benefits, healthcare, education…

Government spending shock influences directly on the output of the economy. The percentage increase by the output level is determined by the value of the parameter g/y. In this model g/y=0.39, implying that a 1% increase of the government spending shock would result into an increase of output of 0.39%. However, this increase is limited by the decrease of the consumption which will be later discussed.

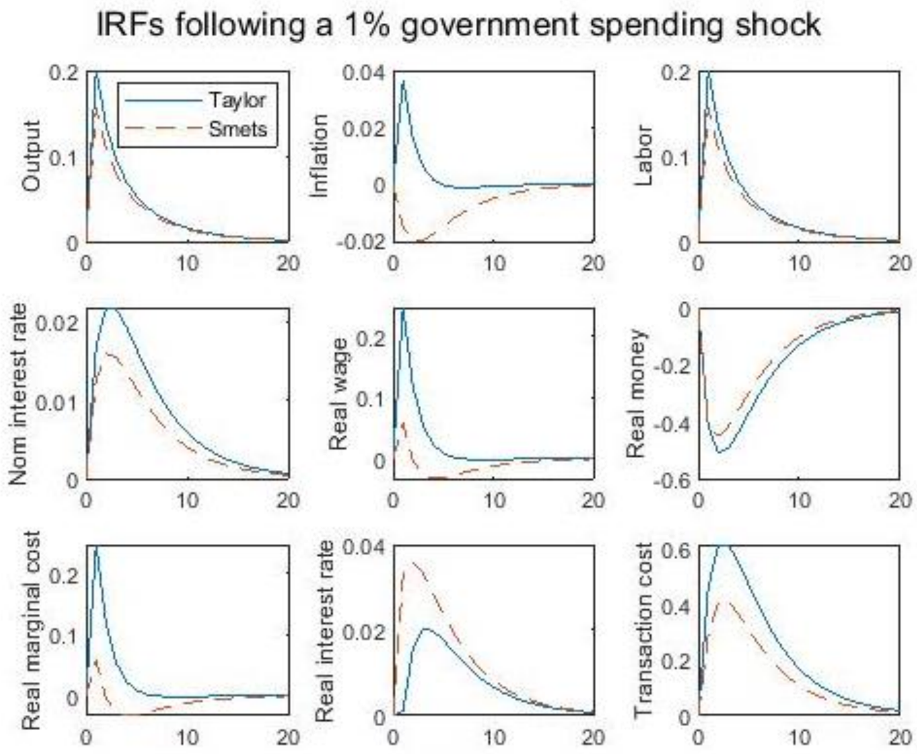

Figure 3. Government spending shock. Obtained from MatLab

Government spending more money is translated into more jobs created, especially those associated with the public sector. See that in this model due to the linearity of the production function, labour increase in the same percentage as output does.

The increase in the demand for job is translated into higher wages, which will increase firms' variable cost, so will the marginal cost. Those greater cost that firms face, are translated to the consumers by greater prices, increasing the economy price levels.

Central bank will try to stabilize the output level, increasing the nominal interest rates. Real interest rate will also increase but at a lower level as inflation expectation mitigate the effect of nominal interest rate. Opportunity cost of holding money increase, so population will decrease their money holds.

Having less money on their pockets will make people more prone to ask for credits, loans… which will increase their transaction costs.

The increase in real interest rate plus the rose of transaction cost makes consumption attractiveness to decrease. The decrease of consumption counteracts the increase of government spending, so output does not increase the 39% that one may suppose at first.

4.3 Monetary policy shock

Thirdly, we will analyse the impulse response functions associated with the monetary spending shock. It is created by the central bank when it changes without warning, either the money supply or the interest rate. In the model money supply does not appear, so the analysis will focus on the increase of the interest rate shock in 1%.

In other cases, we have an AR (1) process, and the present effect of the shock is translated to the future value of the shock, making the effect on the economy last longer than in this case. Monetary spending shock is a white noise process, so it makes the effect last less than for other shocks.

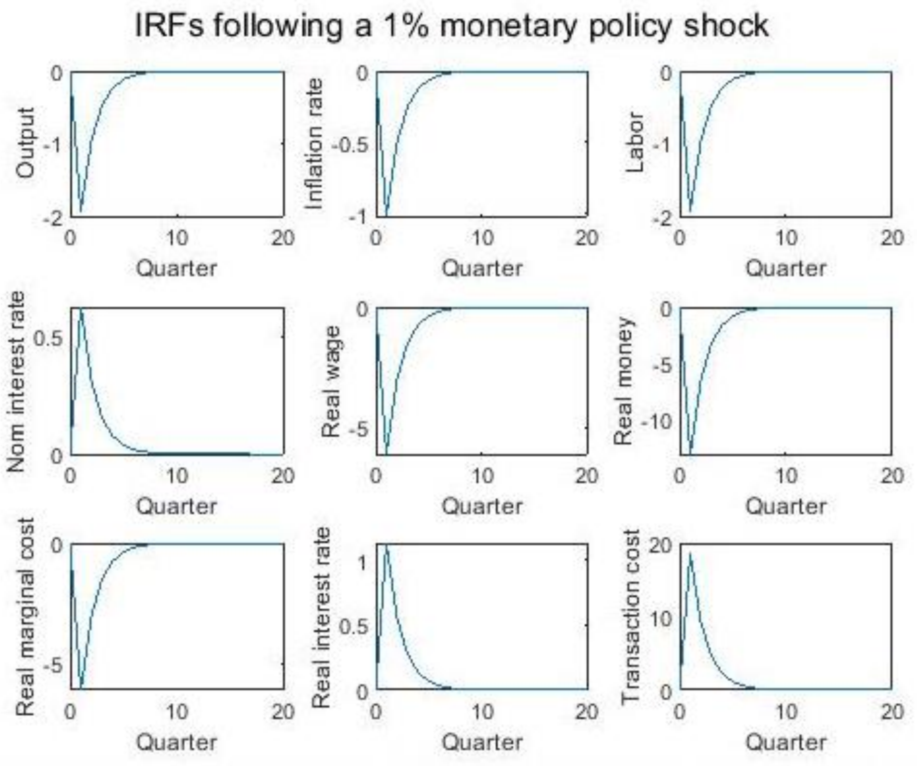

Figure 4. Monetary policy shock. Obtained from MatLab

Monetary spending shock affects directly to the nominal interest rate, as expressed by Taylor (1993). In this case we observe that an increase in 1% of interest rate shock leads to an increase of 0.6% of the nominal interest rate.

Opportunity cost of real money increase because interest obtained by holding bonds increase. Therefore, more people will be willing to spend money in buying this kind of assets, decreasing their money holdings.

Moreover, an increase of the nominal interest rate is translated into an increase of the real interest rate.

The increase of the real interest rate affects consumption levels, representing the opportunity cost of the consumption. Money used for consumption could have been used for other purposes, such as for buying bonds. If bonds are more appealing, as the interest they give are higher, people would devote part of the money that they would have use for consumption for buying bonds. Consumption is associated to the output level; their connection is explained by the overall resource equation. The lower the consumption, the lower the output would be.

Even though consumption has decreased, transaction costs are increased greatly. The explanation resides in the greater decrease of real money.

Lower output levels implies that firms do not need that much labour as they need to produce less goods, so the workforce will be reduced. Firing workers implies that the real wage of the rest of the employees will be reduced

Furthermore, the decrease in the real wage makes the real marginal cost decrease. Lower salaries paid to employees implies that the variable cost faced by the firms are decreased.

Lower marginal cost implies a decrease in prices, as firms always seek to be more competitive in the market. The decrease in prices is translated into deflation.

The lack of persistence of this shock is key to explain the short time needed to return to equilibrium. Once the shock disappears, which corresponds to period 2, the nominal interest rate starts to decrease going back to the initial situation, it goes back slower to what may be thought at first due to the introduction of the smoothing interest rate in the Taylor rule. Once it occurs, everything goes back to equilibrium.

4.4 Inflation shock

When we have explained in the price aggregation equation, firms are able to set optimal prices with a probability $1-\eta$. With a percentage η, firms are not allowed to set optimal prices, so they perform the indexation of last period price to set the price. Indexation mean to the inflation adjustment, and it is based on the sum of the steady state inflation and the inflation shock.

In this section we will analyse the effect of a 1% increase in the inflation shock. As a result of the inflation shock, prices that are not able to set the optimal price will increase their price level, increasing the aggregate price level.

This shock is of special interest for us due to the present economic situation. Due to certain events like the war between Ukraine and Russia or the huge bottleneck that the supply side has suffer due to the COVID-19 crisis, inflation shock is very present on our daily life.

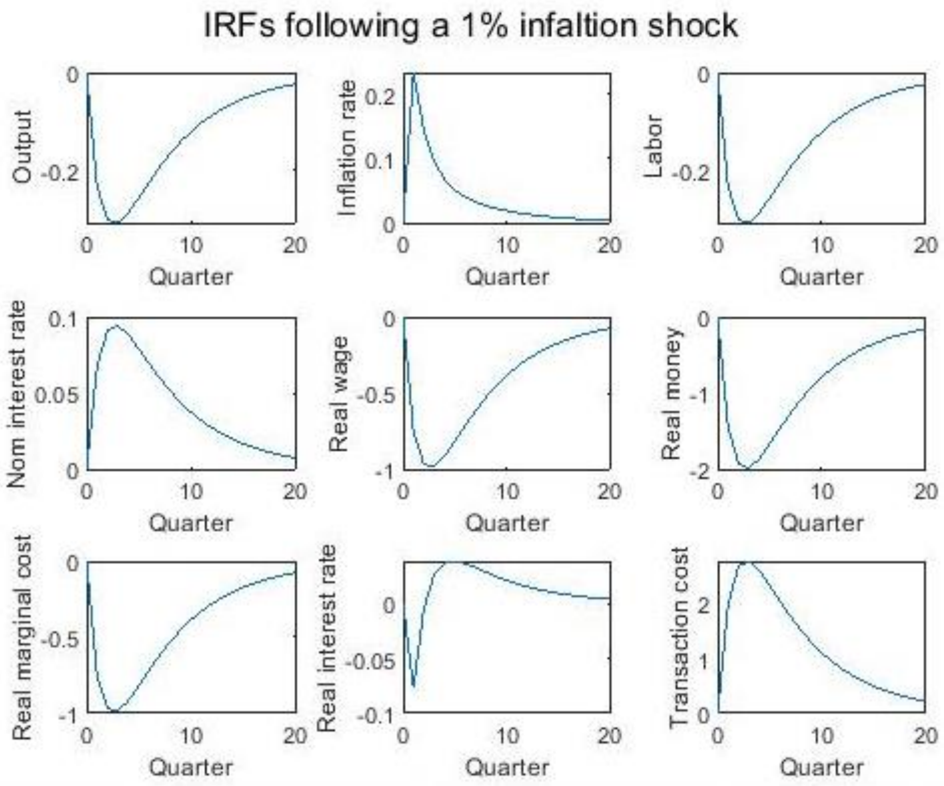

Figure 5. Inflation shock. Obtained from MatLab

Inflation shock as its name indicates has a direct effect on the inflation rate, so inflation of period 1 will increase. In this case we see that a 1% increase in the inflation shock. However, we see that the inflation increases at a lower level. The reason is that those firms that can set the optimal price, will do it influenced by not only the actual marginal costs, but also by the future ones. As marginal cost is expected to decrease more, they will set lower prices. Why is not inflation a negative number then? Because those firms that cannot set the optimal price must adjust it to the indexation rule, which has increased due to the greater inflation shock, so the price of their products will be higher. Being those firms the majority, 75% of the firms (because $\eta = 0.75$), make overall price level to increase.

According to the Taylor Rule, an increase in the inflation rate will be translated into an increase of the nominal interest rate.

Higher nominal interest rate would lead to an increase of the real interest rate. However, positive expectation of inflation rate counteracts the aforementioned effect and lead to an initial decrease of the real interest rate.

Nevertheless, the effect of the nominal interest rate goes far beyond, affecting negatively to the real money holdings. It makes sense, as interest represents the opportunity cost of money holding, so the greater the nominal interest rate is, the lower money agents will hold.

Referring to transaction costs, we observe an increase. The intuition behind that is that real money holding has decreased sharply, which make agents rely more on credits or loans, increasing the transaction cost.

Firms are aware that increasing the price has a cost, which is a reduction of the demand for their products. Consumption will decrease if the inflation level is positive, as well as output level.

On account of that, those firms need less workers because their production levels should decrease to meet the lower demand. Real wage will decrease as firms demand less labour and workers supply the same amount as before.

This will influence the marginal cost, which will be reduced in the same amount that the real wage does.

Returning to equilibrium levels is done by the decrease of the inflation shock. Firms that cannot change the price, period by period set lower prices due to the decrease of the inflation shock. This added to the decrease of the marginal cost, which implies that firms are more competitive and can set lower prices. Firms are interested in doing so, because if other decrease the price and they keep them high, they will loss even more market share. Lowering prices will lead to the reduction of the inflation levels.

5 ALTERNATIVE TAYLOR RULE PARAMETERS

In our initial model, instead of performing a Bayesian estimation for calibrating the parameters, we have taken them as given basing on different essays. One of the most important ones is Taylor´s one, as it gives the coefficients for the Taylor Rule. Despite the clarity and simplicity of the proposed equation, Taylor rule has aroused controversy on the grounds that it was inspired on US economy and is has been used by researchers for other economies. Peersman and Smets (1999) claims that a central bank would never commit to such a simple rule. He argues that the rule is too restrictive, which is the cost paid for the simplicity, as the list of variables is limited to three. Moreover, changes in the economy structure may make the rule usefulness.

On a general basis, emerging countries tend to put much more attention on stabilizing inflation than output. This explains the huge volatility shown in countries like Chine during the previous decade, with percentage of GDP growth near the 10%. With the purpose of defending their ideas, Taylor (2000) concluded that for emerging countries some modifications on the parameters may be required, but that the rule can perfectly suit those economies.

Notwithstanding, many authors claim that optimal parameters should be much higher. Among these authors we find Rudebusch and Svensson (1998), who argue that parameters of inflation and output gap should be greater than two in both cases; Levin (1996) found that a better stabilization of both output and inflation occurs when both parameters take a value of two; Ball (1999) argues that the parameters suggested by Taylor are lower than the optimal ones. All of them conclude that central bank does not respond more to inflation than to the output gap, which contradicts Taylor essay.

The same conclusion was extracted by Peersman and Smets (1999), when they analysed the Taylor rule for the European Union, they claimed that the European bank is more worried about output gap than what Taylor proposed.

The alternative chosen is presented by Smets (2002). It proposes $\mu_y = 2.06/4$ and $\mu_\pi = 1.34$. The alternative will maintain the interest rate smoothing, because if not, inflation shock will disappear the period after it occurred.

5.1 Comparison using artificial series

In reality things are not as easy as explained in the 4th section, different shock may appear at the same time and with different values.

Given this circumstance, we will simulate artificial series with 2000 iterations each having 200 simulated observations, where the shocks occurred randomly, and the value of these shocks are also random numbers. The random number surges of a normal distribution of mean zero and standard deviation equal to one.

Once the simulation is performed, we can extract interesting 2nd moment statistics, 3 different types of statistics can be extracted, which will be used for comparing both models. Comparison is done for finding the model which goes along with central bank objectives, interest, output and inflation stabilization. The objective of stabilizing output may be not fully understood at first sight. Why would a central bank refuse the possibility of growing more? The reason behind is that the institution prefers a low growth compared to having a huge volatility, periods where the economy grow a lot and others where they face crisis periods. Moreover, high growth periods also lead to tensions because price level also increase sharply.

Firstly, standard deviation is obtained, which represents the volatility of the variable. Having a big standard deviation, implies that that variable can oscillate in a great range of values. Being the central bank a lover of the stability, it is appropriate to check the effect of the change in the monetary policy parameters on the stability of the economy, putting special attention to output and inflation rates.

Variables	**Standard Deviation M1**	**Standard Deviation M2**
y_t	$\sigma_{y_t} = 0.8745$	$\sigma_{y_t} = 0.9328$
c_t	$\sigma_{c_t} = 1.3314$	$\sigma_{c_t} = 1.6552$
n_t	$\sigma_{n_t} = 0.6883$	$\sigma_{n_t} = 0.6615$
w_t	$\sigma_{w_t} = 1.9195$	$\sigma_{w_t} = 1.8114$
R_t	$\sigma_{R_t} = 0.2496$	$\sigma_{R_t} = 0.6931$
r_t	$\sigma_{r_t} = 0.2783$	$\sigma_{r_t} = 0.3506$
π_t	$\sigma_{\pi_t} = 0.3393$	$\sigma_{\pi_t} = 0.9558$
mc_t	$\sigma_{mc_t} = 1.8924$	$\sigma_{mc_t} = 2.0853$
$\not{f}_{n_t}$	$\sigma_{\not{f}_{n_t}} = 0.6960$	$\sigma_{\not{f}_{n_t}} = 0.6960$
m_t	$\sigma_{m_t} = 5.3206$	$\sigma_{m_t} = 12.634$
h_{c_t}	$\sigma_{h_{c_t}} = 15.978$	$\sigma_{h_{c_t}} = 44.355$
h_t	$\sigma_{h_t} = 7.3269$	$\sigma_{h_t} = 21.415$

Table 1. Standard deviations of endogenous variables for both models. Obtained from MatLab

As mentioned before, it is crucial to observe what happens to the volatility of inflation and the output gap. In the alternative model (M2) the volatility of inflation is greater than it was in the initial model (M1), which can be explained by the decrease of importance of inflation stability compared to the initial model. In M1 $\mu_{\pi} = 1.5$ while in M2 is 1.34, which means that central bank will react stronger to inflations changes in the first model, remember that central bank instrument in the model is the nominal interest rate. Consequently, why does not nominal interest rate volatility decrease from M1 to M2? The reason is that central bank reaction to output gap changes, has been incremented $\left(\mu_{\mathrm{y}}(\mathrm{M1}) = \frac{0.5}{4} < \mu_{\mathrm{y}}(\mathrm{M2}) = \frac{2.06}{4}\right)$, and the volatility of this variable is greater than the one of inflation.

Strikingly volatility of output has risen, one would expect that the central banks giving more attention to output stability will lead to lower volatility, however it does not because of the increase in the volatility of consumption, and the effect it exercises according to the consumption Euler equation.

It is interesting to observe how the stability of household's changes. On the one hand labour hours become a little bit more stable, so do the real wages due to their huge correlation. One would have expected labour being more volatile, due to the linearity with output, but the fact is that the covariance between labour hours and the technology shock made labour hours stabilize more in the second model. On the other hand, consumption levels, money hold and transaction cost rose their volatility, especially the latter, their volatility has risen due to the increased in the volatility of the nominal interest rate.

In the case of firms, marginal cost is more volatile despite the stabilization of wages. Otherwise, productivity value remains unchanged.

Despite both variables of interest, inflation and output has risen their volatility is absolute terms, in relative terms, $\frac{\mu_{\mathrm{y}}}{\mu_{\pi}}$, output level volatility has decreased.

Secondly, we have the correlation between endogenous variable and the output level. This information explains the connection between the variables, giving information about the sign of the correlation as well as the degree of importance for explaining output level. This information is associated with the term procyclicality, which describes how a variable fluctuate around a trend during a business cycle. Procyclical variables are those that increase during a period of expansion and decrease when the economy is slowing down. While countercyclical variables are the variables that increase when the economy is on a recession and decrease when the economy is booming.

Variables	Corr with output level M1	Corr with output level M2
yt	Corr(yt,yt)=1	Corr(yt,yt)=1
ct	Corr(ct,yt)= 0.7485	Corr(ct,yt)=0.8106
nt	Corr(nt,yt)= 0.6180	Corr(nt,yt)=0.6672
wt	Corr(wt,yt)= 0.8370	Corr(wt,yt)=0.4658
Rt	Corr(Rt,yt)= -0.8027	Corr(Rt,yt)=-0.86041
rt	Corr(rt,yt)= -0.4904	Corr(rt,yt)=-0.1283
πt	Corr(πt,yt)= -0.0568	Corr(πt,yt)=-0.57682
mct	Corr(mct,yt)= 0.6118	Corr(mct,yt)=0.1753
$\oint nt$	Corr($\oint nt$,yt)= 0.6214	Corr($\oint nt$,yt)=0.6866
mt	Corr(mt,yt)= 0.7899	Corr(mt,yt)=0.8617
hct	Corr(hct,yt)= -0.8027	Corr(hct,yt)=-0.8604
ht	Corr(ht,yt)= -0.8072	Corr(ht,yt)=-0.8596

Table 2.Correlation between endogenous variables and output level for both models.Obtained from MatLab

Correlation is a statistical parameter that expresses the extent to what two variables are linearly related. It can take a value between -1 and 1. The greater the value in absolute terms, the greater the greater the relationship between both. Zero correlation implies no connexion between both.

In our models the procyclical variables are:

- Consumption level: In expansion periods financial situation of households becomes better, so they can spend more money on consuming goods.
- Labour hours: Employment rate is positively associated with the output level, firms need to produce more at good times, so they will need more employees.
- Real wage: As explained above labour demand increase, and it empowers worker´s negotiation position.
- Marginal cost: It rises in expansionary periods because the variable cost (employee wages) rise.
- Productivity of workers: Good economic situations foster investments, which in some cases will be translated into innovation which enhance worker´s productivity.

- Real money holdings: Good economic climate make people increase their revenues and therefore have more money.
- Output level: It is the representation of the economic situation, so it obviously a procyclical variable.

Countercyclical are:

- Inflation: The level of correlation is given by the reaction to both variables during shock periods. Inflation and output have a positive correlation when there is either government spending shock or a monetary policy shock. Notwithstanding, the correlation is negative when there is a technology shock or an inflation shock. As all shock occurred randomly, the correlation will be given by the shock with greater influence on output level, which is undoubtedly the technology shock, so the correlation is negative.
- Nominal interest rate: Something similar occurred with the nominal interest rate. Correlation between both variables is negative for all shocks with the exception of the government spending one. We can conclude that an increase of the nominal interest rate results in a decrease of the output level after some periods. The increase of correlation between both variables is explained by the increase of the parameter μ_y. We can see that there is a huge correlation between both.
- Real interest rate: The correlation between real interest rate and output level is negative. The reason behind is that opportunity cost of consuming rises when interest rates increase. Theory argues that lower consumption will be translated into lower output levels.
- Transaction cost: Previously was said that greater output level, leads to greater money holdings and greater consumption levels. Consumption has a negative relationship with transaction cost, whereas money holding has a positive relationship. The negative correlation between transaction cost and output level, is explain by the fact that money holding has a greater influence on the transaction cost, due to its greater value and greater volatility.

All the values of the correlation with output have increased, except for real wage, real marginal cost and real interest rate. The correlation is stronger as the change in parameters implies that the monetary institution is more worried about output stabilization, hence all variables are indirectly affected in order to follow a similar path as output does. Lower correlation is found for the real wage because the volatility of the variable has decreased, so it fluctuates around a shorter range of values. If the output moves drastically, the real wage will not follow output´s path as much as it previously does. Lower wage correlation will also translate into lower marginal cost correlation due to the huge influence exercised by the former on the latter.

Finally, we get the autocorrelation of the variables, which shows the persistence of the variable from one period to the other. Greater inertia implies that today´s variable value is closer to last period value.

Variables	**Autocorrelation, M1**	**Autocorrelation, M2**
y_t	Corr(y_t, y_{t-1})= 0.7884	Corr(y_t, y_{t-1})=0.8486
c_t	Corr(c_t, c_{t-1})= 0.8151	Corr(c_t, c_{t-1})=0.8835
n_t	Corr(n_t, n_{t-1})= 0.6647	Corr(n_t, n_{t-1})=0.6087
w_t	Corr(w_t, w_{t-1})= 0.6738	Corr(w_t, w_{t-1})=0.5371
R_t	Corr(R_t, R_{t-1})= 0.7952	Corr(R_t, R_{t-1})=0.9473
r_t	Corr(r_t, r_{t-1})= 0.5047	Corr(r_t, r_{t-1})=0.4807
π_t	Corr(π_t, π_{t-1})= 0.6123	Corr(π_t, π_{t-1})=0.8157
mc_t	Corr(mc_t, mc_{t-1})= 0.6497	Corr(mc_t, mc_{t-1})=0.5791
$\not{f}_{n_t}$	Corr($\not{f}_{n_t}, \not{f}_{n_{t-1}}$)= 0.9263	Corr($\not{f}_{n_t}, \not{f}_{n_{t-1}}$)=0.9259
m_t	Corr(m_t, m_{t-1})= 0.8004	Corr(m_t, m_{t-1})=0.9442
h_{c_t}	Corr($h_{c_t}, h_{c_{t-1}}$)= 0.7952	Corr($h_{c_t}, h_{c_{t-1}}$)=0.9473
h_t	Corr(h_t, h_{t-1})= 0.7933	Corr(h_t, h_{t-1})=0.9479

Table 3. Autocorrelation of endogenous variables for both models. Obtained from MatLab

Explained by the fact that in that model the central bank is less worried about the inflation stabilization, greater persistence is found in the alternative model for the inflation rate. In the second model, if the inflation is high, as there is not that much pressure to put it back into steady state, the variable may continue in similar values for a long time. Central bank response is not as aggressive as it was originally in the first model, consequently, the levels on inflation will not variable much from the last period.

Output level correlation has increased, and we were expected to decrease. However, the effect is very small. The important reason is that in relative terms, output levels autocorrelation has decreased compared to the inflation autocorrelation, which is the intuition of the change in parameters.

5.2 Impulse-response functions comparison

For better understanding the effect of this change in the Taylor rule´s parameters, a graphical comparison the evolution of the four impulse-response functions for both models is provided.

For differentiating both models, we will make use of two-line shapes. The continuous line represents the evolution of variable´s values for the original model, the one with Taylor (1993) proposed coefficients. Whereas the dotted line represents the evolution of variable´s values for the alternative model, with Smets (2002) coefficients for the Taylor rule.

5.2.1 Technology shock

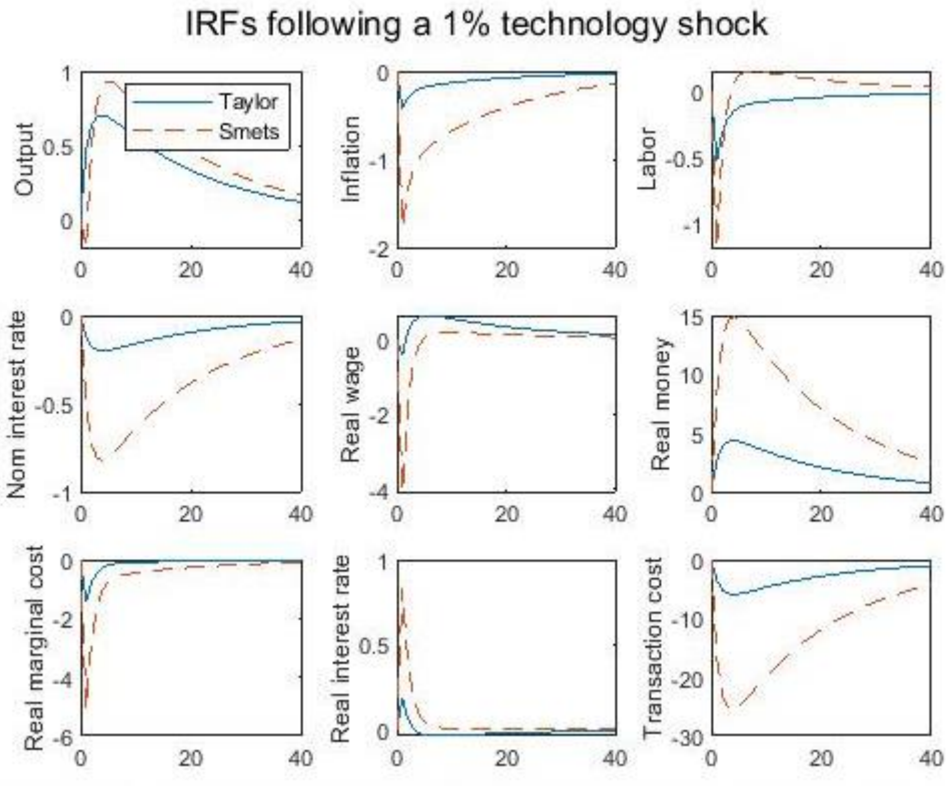

Figure 6. Technology shock for both models. Obtained from MatLab

All effects seem to be amplified in the alternative model, as greater deviations from the steady state occur.

We see that the output gains due to the rise of productivity reside for a longer time, implying that the pick of output is greater than it was in the original model. This can be explained by the greater standard deviation of the variable for this alternative. The prolonged output rise makes the labour demand to fall deeper, as firm does not feel the need to rise their workforce if they are producing more.

Translation into real wage is immediate, lower demand of employees is translated into lower salaries. In the original model, the decrease of labour was so short that it even allows wages to rose. In the alternative model, wages decrease sharply, preventing them to become greater than in the initial situation when the economy goes back to the steady state.

The massive drop of wages plus the rise of productivity are translated into a decrease of marginal cost which exceed by far the one of the original model. It is translated into a stronger period of deflation. Central bank is not as worried as it was in M1 for inflation, so inflation levels should be more worrying than before for the institution to take measures.

Given the new situation, central bank actions must be more severe, than it was on the original model. Nominal interest rate drops to -0.75% per quarter, showing the negative correlation between output and nominal interest rate. Real interest rate also decreases and so will money holdings.

To sum up, the original model proportionates a much more stable environment when a technology shock occurred, which goes along with central bank objectives. Alternative model brings to greater output levels, but on the expense of greater deflation.

5.2.2 Government spending shock

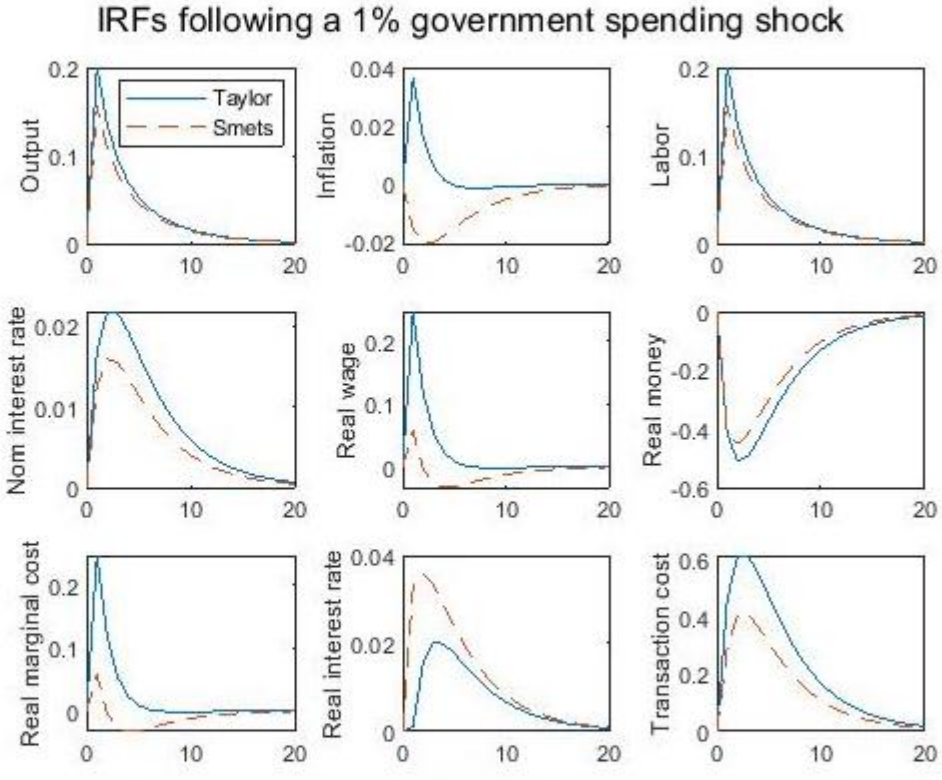

Figure 7. Government spending shock for both models. Obtained from MatLab

Government spending shock on the alternative model has a lower influence on output levels than it does for the original model. This can be explained by the fact that real interest rate increases more and faster in the alternative model, which implies that the decrease in consumption comes earlier and is stronger. Lower output levels imply lower increase in labour.

Nominal interest rate starts to rise at the same pace, but the decrease in inflation levels stops the increase of the interest. The decrease on inflation is explained by the fact that firms are forward looking, so those enable to change their prices would anticipate the negative values that the real marginal cost would take from period 2 till period 6 and would reflect this by decreasing prices. In the M1, that does not occur as the marginal cost is never in negative values.

Wage´s movement can be explained by the lower correlation of the variable with the output level, in the alternative model output increases lead to a lower increase of wages, plus the fact that labour demand has not increased as much as in the initial model. Moreover, wage lower volatility is also crucial for explaining its stagnation.

Money holding levels are an interesting topic. Their decrease in the alternative model is lower than the one faced in the original model, in spite of being consumption lower in the alternative model. Hence, the explanation comes from the part of nominal interest rate. The fact that its increase is lower in the alternative is the cause of the money holding to decrease less in the alternative model.

5.2.3 Monetary policy shock

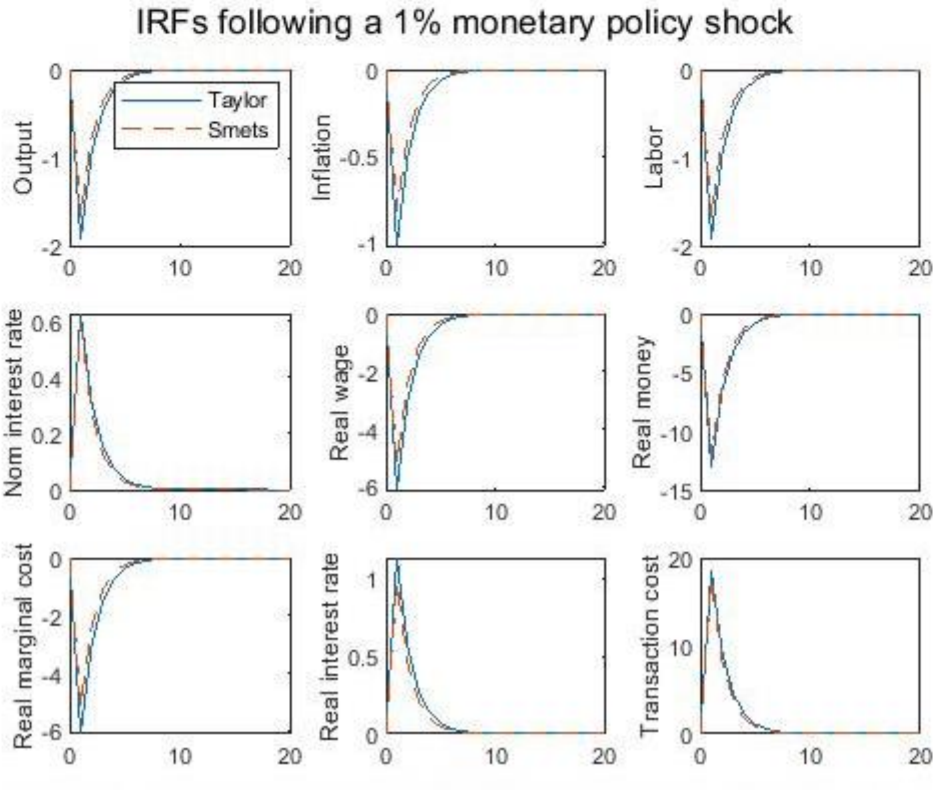

Figure 8. Monetary policy shock for both models. Obtained from MatLab

The fact that the smoothing interest coefficient (μ_R) is the same for both models, makes this impulse response functions be quite identical for both models.

5.2.4 *Inflation shock*

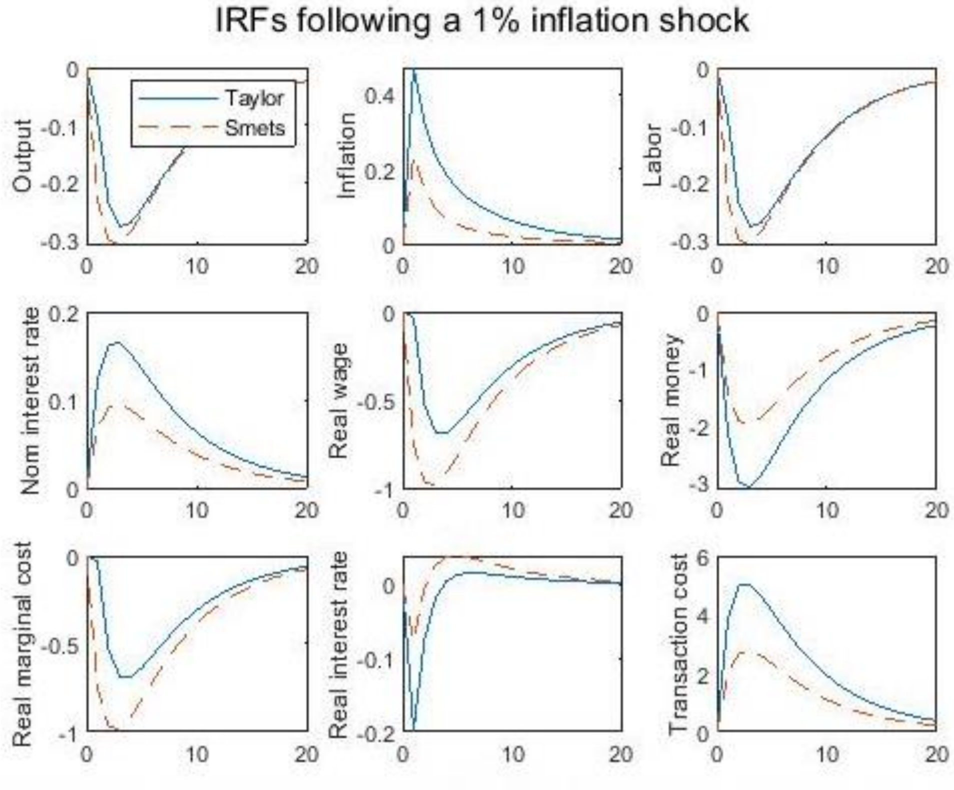

Figure 9. Inflation shock for both models. Obtained from MatLab

In the model inspired on Smets parameters, the inflation shock drive into a lower increase in inflation shock. The explanation goes along with the idea of forward-looking firms explained in the government spending shock. Now those firms that can set an optimal price will set a lower one, because the decrease in the real marginal cost in the second model is greater. Lower real marginal cost is explained by lower real wage in the alternative model.

Being the red line below the blue line in the nominal interest rate graph is explained by the lower attention the monetary institution puts on inflation stability and the fact that the inflation has increased less in the red line associated model.

Real interest rate initial decrease less in the alternative model, as inflation expectation in this model are lower. If we add the prolonged increase in the nominal interest rate, the conclusion result is a real interest rate that after the third period becomes positive.

Inflation negative correlation with output implies that when the inflation increases, output levels should decrease. The fact that in the second model, the correlation is greater implies that the effect will sooner appear in the output levels. This makes unemployment rate to rise sooner, wages to sooner decrease and real marginal cost to decrease at a greater speed.

6 CONCLUSION

The model incorporates four different agents: households, firms, government and the central bank. Households and firms act as rational agents with the objective of maximizing their welfare and profit, respectively. The central bank is worried about the macroeconomic stabilization of output and inflation, while the government faces a budget constraint to finance the exogenous amount of public expenditures that is decided.

Furthermore, it is particularly interesting in this academic level due to the way of introducing money, with the transaction costs. In most of the model of this scientific literature, money tend not to be included, but if it is included is usually done in the utility function simplifying things. A transactions-facilitating role of money is closer to the reality than the introduction of money in the utility function.

This paper incorporates points of view of reputed economist during the calibration, going in line with the economic trend of New Keynesianism, which is the school of thought for most of the countries, especially western ones.

When it comes to model comparison, it goes without saying that the original model, with the parameters suggested by Taylor, is closer with the central bank objectives. It has lower volatility on both important variables, output and inflation. This goes in line with what has been seen in the impulse response function comparison, especially on the technology shock which is the most important due to its greater effect on the economy, due to its longer persistence.

The essay has successfully achieved the initial objectives of a better understanding of agent's behaviour and economic fluctuation, as well as comparing two alternative specifications of the Taylor Rule proposed by different economists.

Nonetheless, the model has limitations which makes it being a simple model. For further research, it would be interesting including capital accumulation, sticky wages or the idea of decreasing productivity for obtaining a more realistic model. Moreover, carrying out a comparison of the original model, with another where the central bank is even more concerned about price inflation stabilization may be interesting.

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