Department of Economics

Athens University of Economics and Business

WORKING PAPER no. 15-2022

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July 2022

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Abstract

This paper develops a medium-sized monetary dynamic stochastic general equilibrium model of unemployment which features costly state verification financial frictions. The labor sector of the model consists of an insiders-outsiders labor market structure where a monopoly labor union unilaterally sets the nominal wage according to a hysteresis equation. The main purpose of the paper is; firstly, to explore how labor market hysteresis affects the persistence of macroeconomic aggregates after temporary aggregate shocks that simulate a financial crisis; secondly, to investigate the implications of hysteresis for monetary policy. Overall, it is highlighted that a DSGE model that incorporates both financial frictions and employment hysteresis can generate substantial endogenous persistence that resemble a severe financial crisis. Furthermore, welfare analysis indicates a Taylor policy that stabilizes the growth rate of output leads to heavy welfare losses relative to output gap targeting. These losses increase with the degree of hysteresis. In this case, a central bank can benefit from choosing to stabilize wage inflation.

Keywords: financial frictions, insiders-outsiders, hysteresis, monetary policy.

JEL classification numbers: E24, E32, E52.

This research did not receive any specific grand from funding agencies in the public, commercial, or non-for-profit sectors.

Declarations of interest: none.

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1 Introduction

During the past decade DSGE models have been the target of heavy criticism due to their failure to predict the financial crisis of 2008-2009. This weakness of DSGE models was attributed to their lack of a financial sector characterized by frictions that could account for key factors that led to the financial crisis. Nevertheless, this criticism was not totally justifiable since early efforts to incorporate financial frictions into dynamic macroeconomic models had already started since the late 1980s with Bernanke & Gertler (1989), Bernanke & Gertler (1990), Holmstrom & Tirole (1997), Iacoviello (2005) and the seminal papers of Kiyotaki & Moore (1997) and Bernanke et al. (1999).

A second "wave" of DSGE models with financial frictions emerged right after the financial crisis unraveled. For instance, Mendoza (2010), Meh & Moran (2010), Gertler & Kiyotaki (2010), Gertler & Karadi (2011), Cúrdia & Woodford (2010), Cúrdia & Woodford (2011), Jermann & Quadrini (2012), Kiyotaki & Moore (2012) and Iacoviello (2015) among many others. These models highlighted elaborate mechanisms for endogenously incorporating frictions either in the demand or in the supply for credit. Despite their different starting points all aimed towards a common goal, to generate an endogenously determined "gap" in the cost of internal versus external financing. More specifically, financial frictions result in a higher cost of external versus internal financing due to the costs of processes associated with obtaining external funding. In most cases a "financial accelerator" effect is highlighted; meaning that the presence of financial frictions generates more endogenous persistence relative to a financially frictionless version of the model. Brunnermeier et al. (2012), Christiano et al. (2018) and Gertler & Gilchrist (2018) present analytical surveys of this literature.

However, criticism to DSGE models is not constrained to their lack of an active financial sector. For instance, Blanchard (2017) criticizes the current approach to macroeconomics which focuses on one-distortion (nominal rigidities) and one-instrument (nominal interest rate). Within this framework maintaining a constant and low inflation leads to the "divine coincidence"[1], i.e., simultaneously minimizes distortions and leads to the right level of output. In addition, he claims that this simplistic approach was proven inadequate when the financial crisis of 2008-2009 arose; and it became clear that the financial sector was much more central to macroeconomics than had previously assumed. Blanchard (2017) supports that even the simplest models should incorporate more distortions and policy instruments. He proposes three distortions as central even for the simplest models: nominal rigidities, finite horizons, and financial frictions.

[1]Blanchard & Galí (2007) introduced the term "divine coincidence" to describe the absence of a trade off between real output and inflation stabilization that characterizes the baseline New Keynesian model.

Alogoskoufis (2019) stresses two weaknesses of the baseline New Keynesian framework. First, the absence of endogenous output and inflation persistence. He argues that the empirical performance of the New Keynesian Phillips Curve, which is one of the three equations that make up the baseline New Keynesian model, is unsatisfactory because it does not generate the persistence of inflation and output that is observed in actual data after aggregate shocks. Second, the "divine coincidence". Furthermore, Alogoskoufis (2019) highlights two theoretical shortcomings of medium-sized DSGE models. First, the mathematical complexity and the omission of important market distortions and mechanisms for the sake of theoretical consistency. Second, although some efforts to incorporate financial frictions have been undertaken, many of the present day medium-sized DSGE models continue to rely on perfect financial markets and the "efficient market hypothesis". Aside all of their limitations, Galí (2017) defends DSGE models against criticism by arguing that macroeconomic phenomena like economic fluctuations can only be explained through a dynamic, stochastic, general equilibrium framework.

Regarding the empirical evidence, there are plenty of papers that highlight the high persistence of aggregate macroeconomic data. For instance, Nelson & Plosser (1982) followed by Campbell & Mankiw (1987) and Perron (1988) presented evidence that questioned the mean reverting behavior of US real output after temporary innovations. These studies suggested that shocks to real output are largely permanent. Cochrane (1988) showed empirically that the US real output is in fact stationary, but it reverts to its mean over a time horizon of many years. Diebold & Rudebusch (1989) also found evidence of long memory and high persistence in US real output, suggesting that the rate of convergence to trend is potentially measured in decades. Diebold & Senhadji (1996) supported that the autoregressive root of US real output was likely close, but less than, unity. More recently, Cushman (2016) showed that the hypothesis of a unit root in US real output cannot be rejected.

Furthermore, empirical evidence show that events such as financial crises and deep recessions generate very persistent changes in real output. More specifically, Claessens et al. (2012) using data from 44 OECD and 23 emerging market countries, found that recessions associated with financial crises are longer and deeper relative to other recessions. Jordá et al. (2011) focused on data from 14 advanced countries and showed that financial crises are costlier, tend to be followed by deeper recessions and slower recoveries relative to typical recessions. Reinhart & Rogoff (2014) studied the evolution of real output after 100 systemic banking crises and found that a large portion of the costs of these events laid in the prolonged and halted nature of the recovery. Ball (2014) used data from 23 countries and found that most of these countries have experienced strong hysteresis effects on their real output, after the 2008-2009 global financial recession.

The term hysteresis was first introduced by Blanchard & Summers (1986) to describe the significant persistence of the European unemployment rates after the economic crises of the 1970s and 1980s. Similar empirical results of significant persistence in labor market aggregates have been made earlier by Clark & Summers (1982) and Ellwood (1982); and have also been confirmed by more recent papers, such as Cerra & Saxena (2000), Bluedorn & Leigh (2018) and Bluedorn & Leigh (2019).

It is clear that the empirical literature has produced a strong set of empirical results that emphasizes the persistent nature of fluctuations. A thorough review of hysteresis is not pursued here. The interested reader can find an up-to-date survey on hysteresis in Cerra et al. (2020).

Keeping in mind the aforementioned points and believing that DSGE models should be improved upon rather than discarded, this paper develops a medium-sized monetary DSGE model of unemployment which features financial along with labor market frictions. The goal is to develop a DSGE model that embeds a mix of frictions that could generate strong endogenous persistence for real output, unemployment and inflation, as observed after a financial crisis like the one of 2008-2009. Towards this end, emphasis is given on the role of hysteresis. Firstly, to explore how hysteresis affects the persistence of macroeconomic aggregates after temporary aggregate shocks; secondly, to investigate the implications of hysteresis for monetary policy.

The core of the developed model is based on the baseline hysteresis model developed in Galí (2020), which is transformed towards two main directions. First, to incorporate the features and frictions found in a typical medium-sized New Keynesian model like those of Smets & Wouters (2007) and Christiano et al. (2005). These features are: habit formation in consumption, physical capital accumulation, investment adjustment costs, indexation to previous period inflation for both prices and nominal wages that are not optimally chosen in a specific period, a fixed cost of production that ensures zero equilibrium profits for firms and a monetary authority that conducts policy according to a Taylor rule that allows for policy inertia.

Second, to incorporate the costly state verification mechanism of Bernanke et al. (1999). This mechanism assumes that financial frictions arise in the demand of credit or in other words, between financial intermediaries (banks) and their borrowers (entrepreneurs). The key mechanism of this type of financial frictions involves a link between the "external finance" premium (or the difference between the cost of funds raised externally and the opportunity cost of funds internal to the firm) and the net worth of entrepreneurs. As in Bernanke et al. (1999), the external finance premium is endogenously generated by introducing a conflict of interest (agency problem) between borrowers (entrepreneurs) and their respective lenders (financial intermediaries).

The model economy consists of the following agents: households, intermediate and final good producing firms, capital producers, entrepreneurs, financial intermediaries, a government and a monetary authority. Households supply differentiated labor to intermediate good producing firms in a monopolistically competitive labor market, and make consumption and saving decisions. Intermediate goods producing firms are monopolistically competitive and subject to a Calvo mechanism for price setting. They rent physical capital from entrepreneurs which they then use for production. Competitive final good firms produce using differentiated intermediate goods as inputs. The representative capital producer combines underappreciated physical capital with new investment. Entrepreneurs buy physical capital from capital good producers. Then they rent it to intermediate goods producing firms and re-sell the stock of underappreciated capital, back to capital good producers, at the end of the production cycle, accumulating net worth in the process. Net worth or equity is used to pay for capital in the next production round. However, entrepreneurial net worth is not enough to cover the whole value of capital, so entrepreneurs have to borrow a fraction of the required funds. The representative financial intermediary provides the necessary credit for this funding gap. In turn, the financial intermediary obtains its funds from households' deposits.

Furthermore, following Bernanke et al. (1999) it is assumed that entrepreneurial loans are risky since returns on the entrepreneurial investments are subject to idiosyncratic shocks. A shock with a value lower than some threshold can lead to entrepreneur's bankruptcy. In addition, it is assumed that the idiosyncratic shock is observed by the entrepreneur but not by the financial intermediary; who must pay a fixed monitoring cost in order to observe the entrepreneur's realized return. To minimize expected agency costs caused by this asymmetric information problem, entrepreneurs and the financial intermediary sign a financial contract. According to this contract the entrepreneur commits to paying back the loan principal and a non default interest rate, unless he declares bankruptcy. In the case of bankruptcy, the financial intermediary monitors the remaining value of the entrepreneurial assets and seizes them as a partial compensation. Moreover, the financial intermediary hedges against credit risk by charging a premium over the risk-free rate at which it can borrow funds from households. Finally, the monetary authority sets nominal interest rates according to a Taylor rule that targets to stabilize inflation and the output while at the same time allows for interest rate smoothing.

Overall, the model highlights two distinct financial propagation mechanisms. Both mechanisms work through changes in entrepreneurial net worth or equity. The first mechanism is known as the "financial accelerator" channel and it was introduced in Bernanke & Gertler (1989), Bernanke & Gertler (1990) and Bernanke et al. (1999). It works by altering the net worth of entrepreneurs through changes in the flow of their earnings due to idiosyncratic shocks and by capital gains and losses on their assets due to changes in the price of capital. This channel tends to magnify the macroeconomic effects of aggregate shocks.

The second financial propagation mechanism is known as the "Fisher deflation" channel and arises when debt in the financial contract is formulated in nominal terms. It is highlighted, among others, in Christiano et al. (2010) and Villaverde (2010). This mechanism works through the movements in entrepreneurial net worth that take place when an unexpected change in the price level alters the real entrepreneurial debt. The Fisher and financial accelerator propagation mechanisms reinforce each other after aggregate shocks that move inflation and the price of capital goods towards the same direction. However, the two channels tend to cancel each other out when an aggregate shock pushes inflation and the price of capital goods towards opposite directions.

Moreover, unemployment is modeled in the extensive margin as in Galí (2011b) and Galí (2020). The adopted definition of unemployment is based on the existence of a positive wage markup that pins down the long-run unemployment rate to a specific positive value, along with the existence of nominal wage frictions that generate the fluctuations in the unemployment rate in response to aggregate shocks.

As far as the labor market is concerned, many theories have been proposed to explain the high persistence of (un)employment. The present paper follows the theory proposed by Blanchard & Summers (1986), which is based on the interest conflict between insiders and outsiders in the labor market driven by the segmentation of the labor force. More specifically, the modeling of insiders-outsiders is based on two assumptions. First, the labor force is segmented between those employed, called insiders, and those unemployed, called outsiders. A monopoly labor union that represents insiders, unilaterally sets the nominal wage so as to ensure employment for its members. Second, a hysteresis equation which implies that the measure of insiders endogenously evolves over time as a function of employment. When full hysteresis is assumed, the unemployment rate, employment and output are characterized by unit root behavior. In this case, temporary shocks have permanent effects on these variables. On the contrary, when no hysteresis is assumed, it follows that even after a strong temporary shock, (un)employment quickly reverts to its steady state value.

Two aggregate shocks are introduced, a monetary policy shock, and a financial shock modeled as an unexpected decrease in the survival probability of entrepreneurs. Both shocks are relevant to the onset of financial crises. Regarding the monetary policy, two policy rules are considered. Both of them target price inflation and either the output gap or the quarterly growth rate of real output. Quantitative results are compared against; first, a competitive labor market where labor demand is determined solely by firms; with households supplying freely labor to cover this demand. Second, a standard Calvo nominal wage rigidities labor market structure.

Results suggest that a DSGE model that incorporates financial frictions and labor market hysteresis can generate strong endogenous persistence for real output, (un)employment and inflation after the examined aggregate shocks; comparable to the persistence observed after big macroeconomic turmoils such as the Great Recession of 2008-2009.

Welfare analysis reveals that, a Taylor policy that targets price inflation and the output gap performs well, in terms of welfare, even in the presence of high hysteresis. Furthermore, for high hysteresis, a policy that stabilizes the growth rate of output leads to heavy welfare losses relative to output gap stabilization. These losses increase with the degree of hysteresis. In this case, a central bank can benefit from choosing to stabilize wage inflation.

The rest of this paper is organized as follows. Section 2 presents the model along with a definition for unemployment. Section 3 reports the quantitative results. Section 4 presents the welfare analysis. Finally, section 5 summarizes some concluding remarks.

2 The Model

2.1 Labor Side

As in Galí (2011b), the economy is populated by a large number of identical households of unitary measure. Each household has a continuum of members represented by the unit square and indexed by a pair (j,s) $\in [0,1] \times [0,1]$. Where j $\in [0,1]$, represents the type of labor service that a given household member is specialized in; and s $\in [0,1]$, determines the disutility from work and is given by $\psi^n s^\phi$, where ϕ is the elasticity with which members of labor type j of the household enter or leave employment in response to aggregate shocks and ψ^n is a parameter that determines the disutility from work which is assumed to be constant among labor types.

The representative household maximizes a dynamic utility function that is separable in consumption c_t, employment $n_{j,t}$ and per household government spending $\bar{g}$; and is given by the integral of its members' utilities.

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(c_t - b^c c_{t-1})^{1-\sigma}}{1-\sigma} - \psi^n \int_0^1 \int_0^{n_{j,t}} s^\phi ds dj + \psi^g \frac{\bar{g}^{1-\nu}}{1-\nu} \right) \quad (1)$$

where ψ^g, σ, ν are preference parameters, b^c is a measure of internal habit formation, β denotes the rate of time preference and $\int_0^{n_{j,t}} s^{\phi} ds = \frac{n_{j,t}^{1+\phi}}{1+\phi}$. The household maximizes its intertemporal utility subject to a real period budget constraint of the form

$$c_t + b_t + d_t \leq \int_0^1 w_{j,t} n_{j,t} dj + \frac{1+i_{t-1}^b}{\pi_t} b_{t-1} + \frac{1+i_{t-1}}{\pi_t} d_{t-1} - \tau_t^l + \Pi_t^r + NT_t^r \tag{2}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the quarterly gross inflation rate; b_{t-1} is the end-of-period real stock of government bonds which pay off in period t an unconditioned nominal return known in period t-1, $1 + i_{t-1}^b$; d_{t-1} denotes end-of-period real deposits at the financial intermediary which pay off in period t the nominal interest rate known in period t-1, $1 + i_{t-1}$; $w_{j,t}$ is the real wage for labor of type j; c_t denotes household's real consumption; Π_t^r denotes total real profits in the economy; τ_t^l are real lump-sum taxes/transfers paid by/to the household to/by the government and NT_t^r denotes real net entrepreneurial transfers in period t which are assumed to follow a law of motion that is described in section 2.4.

Each intermediate firm i ∈ [0,1] optimally decides how much labor of each type j to employ by solving a cost minimization problem while taking wages as given. This gives the following sequence of labor demand equations

$$n_{j,t} = \left(\frac{W_{j,t}}{W_t}\right)^{-\epsilon_w} n_t^d \tag{3}$$

∀ j ∈ [0,1], where $n_{j,t} = \int_0^1 n_{j,i,t} di$ denotes the aggregate demand for labor of type j; $n_t^d \equiv \int_0^1 n_{i,t}^d di$ denotes the aggregate demand for labor which is defined as the sum of the demand for labor across all intermediate firms i and $\epsilon_w \in (1, +\infty)$ indicates the elasticity of substitution among labor types. The aggregate nominal wage index W_t is defined as

$$W_t^{1-\epsilon_w} = \int_0^1 W_{j,t}^{1-\epsilon_w} dj \tag{4}$$

The sequences of constraints (2) and (3) are supplemented with a solvency condition which prevents the household from engaging in Ponzi schemes. In other words, a transversality condition on borrowing

$$\lim_{k\to\infty} E_t \left\{ \beta^k \frac{\lambda_{t+k}}{\lambda_t} b_{t+k} \right\} = 0 \tag{5}$$

where $\beta^k \frac{\lambda_{t+k}}{\lambda_t}$ is the real stochastic discount factor and λ_{t+k} is the period t+k Lagrange multiplier from the household's problem. At the optimum, the budget constraint (2) must hold with equality at each date t. The no arbitrage condition dictates that $i_t^b = i_t$, which states that since both i_t^b and i_t are uncontingent and since earnings from neither deposits nor bond holdings is taxed; their returns must be equal in equilibrium. It follows that

$$r_t^b = r_t \ \ \forall\, t$$

where $r_t = \frac{1+i_{t-1}}{\pi_t}$ is the non contingent real net return received by the household at period t for its deposits at the financial intermediary; $r_t^b = \frac{1+i_{t-1}^b}{\pi_t}$ is the non contingent real return received by the household at period t for its holdings of government bonds.

2.1.1 Frictionless Wage Setting

Under a flexible labor market the household chooses the optimal level of employment by equating the real wage to the marginal rate of substitution between labor and consumption,

$$w_t = mrs_t = -\frac{\mathbb{U}_n}{\mathbb{U}_c} = \psi^n \frac{n_t^{\phi}}{\lambda_t} \tag{6}$$

where λ_t is the Lagrange multiplier.

2.1.2 Standard Calvo Wage Setting

Nominal frictions in the labor market are introduced by assuming that nominal wages are sticky in a Calvo (1983) setup. More specifically, $1-\theta_w$ is the probability of a labor type j to be able to reset wages next period and thus, θ_w^k is the probability of a newly set wage at time t, to still be in place at time t+k, ∀ k = 0,1,2,... If wages can not be re-optimized, they are automatically updated according to the following indexation rule $W_{j,t+k|t} = W_{j,t}\left(\bar{\pi}^{\widetilde{\chi}k}\right)^{1-\widetilde{\mu}}\left(\pi_{t-k,t+k-1}^{\widetilde{\chi}}\right)^{\widetilde{\mu}}$ where $W_{j,t+k|t}$ denotes the wage set at period t+k by labor type j who last re-optimized its wage at period t, $\widetilde{\chi} \in [0,1]$ allows for any degree of nominal wage indexation, $\widetilde{\mu} \in [0,1]$ allows for any degree of combination of the two types of indexation; to steady state inflation $\bar{\pi}$ and to past inflation rates. $\widetilde{W_{j,t}}$ is defined as the optimal nominal wage set every period t. When re-optimizing their wage in period t, workers specialized in each occupation j choose a nominal wage $\widetilde{W_{j,t}}$ in order to maximize household utility given by eq. (1), subject to the budget constraint, eq. (2), the demand for labor in the specific market, given by eq. (3) and the probability of not being able to re-optimize in future periods. Solving the maximization problem gives the optimal nominal wage equation

$$\widetilde{W}_t^{\epsilon_w \phi+1} = \frac{\epsilon_w}{\epsilon_w - 1} \frac{E_t \sum_{k=0}^{\infty} \beta^k \theta_w^k \psi^n \left[\frac{\left(\bar{\pi}^{\widetilde{\chi} k}\right)^{1-\widetilde{\mu}} \left(\pi_{t-k,t+k-1}^{\widetilde{\chi}}\right)^{\widetilde{\mu}}}{W_{t+k}} \right]^{-\epsilon_w(1+\phi)} \left(n_{t+k}^d\right)^{1+\phi}}{E_t \sum_{k=0}^{\infty} \beta^k \theta_w^k \lambda_{t+k} \left(\frac{\left(\bar{\pi}^{\widetilde{\chi} k}\right)^{1-\widetilde{\mu}} \left(\pi_{t-k,t+k-1}^{\widetilde{\chi}}\right)^{\widetilde{\mu}}}{W_{t+k}} \right)^{1-\epsilon_w} W_{t+k} P_{t+k} n_{t+k}^d} \tag{7}$$

where $\widetilde{W}_t$ denotes the optimal nominal wage for labor type j which has no j index since all updating workers update to the same nominal wage.

2.1.3 Insiders-Outsiders Wage Setting

In this section, the labor sector of the model is modified so as to allow for the optimal wage to be determined by an insiders-outsiders labor market. The methodology closely follows Galí (2020)[2], who builds upon the framework of Blanchard & Summers (1986). The labor force is segmented between those employed, called insiders, and those unemployed, called outsiders. The former possess a dominant role in the wage determination. An employment target for each period $n_{j,t}^*$, which denotes the number of insiders in the model, is considered. The measure of insiders, or the employment target, in any given labor type j evolves over time according to the hysteresis equation

$$n_{j,t}^* = n_{j,t-1}^{\gamma} \left(n^*\right)^{1-\gamma} \tag{8}$$

where parameter $\gamma \in$ [0,1] determines the extent to which changes in employment affect the economy's state, by changing the portion of insiders. Moreover, n^* is the union's long-run target for employment, which is assumed to be common across labor types. According to eq. (8) when γ = 1, full hysteresis is assumed. Then the unemployment rate, employment and output are characterized by unit root behavior. Temporary shocks have permanent effects on these variables. On the contrary, when γ = 0, no hysteresis is assumed. In this case even after a strong temporary shock (with persistence close to unity), employment quickly reverts to its steady state value.

The steady state level of employment is exogenously determined through the union's long-run employment target, i.e., $n = n^*$. Each intermediate firm i optimally decides how much labor of each type to employ by solving a cost minimization problem while taking wages as given. The problem is the same as in the standard Calvo wage setting. Thus, aggregate demand for labor of type j and the aggre-

[2]Alogoskoufis (2018) presents an alternative way of modeling an insiders-outsiders labor sector, which is based on one period nominal wage contracts. The advantage of Galí's framework is that it can be introduced along with the Calvo (1983) assumption.

gate nominal wage index are still given by equations (3) and (4), respectively. Each union represents a specific labor type j. The union that is able to adjust its wage at period t+k, is sufficiently strong to unilaterally set the wage, $\widetilde{W}_{j,t}$, so as to make expected employment equal to its employment target, determined by eq. (8). The dynamic objective function of the j union is one where it attempts to maximize the intertemporal wage of insiders of type j it represents, subject to their employment being maintained. The discount factor is given by the product of the rate of time preference times the Calvo probability of a union not being able to adjust the wage of labor type j it represents,

$$\min_{\{n_{j,t}\}} \frac{1}{2} \sum_{k=0}^{\infty} (\beta\theta_w)^k \left[E_t \left\{n_{j,t+k|t}\right\} - n_{j,t}^*\right]^2$$

where $n_{j,t+k|t}$ is the t+k period demand for labor of type j whose wage has been optimized for last time in period t, $\forall$ k = 0,1,2... As in the standard Calvo wage setting, wages that are not optimally chosen in a specific period are adjusted to steady state and/or to past inflation according to the indexation rule $W_{j,t+k|t} = \widetilde{W}_{j,t} \left(\bar{\pi}^{\widetilde{\chi}k}\right)^{1-\widetilde{\mu}} \left(\pi_{t-k,t+k-1}^{\widetilde{\chi}}\right)^{\widetilde{\mu}}$. Where $\widetilde{W}_{j,t}$ is the optimally chosen wage at period t for labor of type j. Assuming that all unions which can optimally choose their wage choose the same optimal nominal wage $\widetilde{W}_{j,t} \equiv \widetilde{W}_t$ $\forall$ j,t; the first order condition can be written as

$$\widetilde{w}_t^{\epsilon_w} = (1-\beta\theta_w) \sum_{k=0}^{\infty} (\beta\theta_w)^k \times \\ \times E_t \left\{ w_{t+k}^{\epsilon_w} \left[\left(\bar{\pi}^{\widetilde{\chi}k}\right)^{1-\widetilde{\mu}} \left(\pi_{t-k,t+k-1}^{\widetilde{\chi}}\right)^{\widetilde{\mu}} \right]^{-\epsilon_w} \pi_{t,t+k}^{\epsilon_w} n_{t+k}^d \right\} n_{j,t-1}^{-\gamma} \left(n^*\right)^{\gamma-1} \quad (9)$$

Eq. (9) is the optimal wage setting equation under the insiders-outsiders wage setting setup.

2.2 Production Side

2.2.1 Final Good Producers

The representative final good producer produces final good y_t by aggregating intermediate goods $y_{i,t}$ where i $\in$ [0,1], using a constant elasticity of substitution (CES) production function

$$y_t = \left[\int_0^1 y_{i,t}^{\frac{\epsilon_p - 1}{\epsilon_p}} di\right]^{\frac{\epsilon_p}{\epsilon_p - 1}}$$

where $\epsilon_p \in (1, +\infty)$ indicates the elasticity of substitution among intermediate goods. Solving the profit maximization problem of the competitive final good firm, gives

$$y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\epsilon_p} y_t \tag{10}$$

Eq. (10) implies that the relative demand for the i^{th} intermediate is a function of its relative price, with ϵ_p the price elasticity of demand, and is proportional to real aggregate output, y_t. The aggregate price level is given by $P_t^{1-\epsilon_p} = \int_0^1 P_{i,t}^{1-\epsilon_p} di$.

2.2.2 Intermediate Goods Producers

The i $\in$ [0,1] intermediate producer, produces differentiated output $y_{i,t}$ at price $P_{i,t}$. Production takes place according to a constant returns to scale technology in capital rented by entrepreneurs and labor services rented by households. All intermediate firms i face a common constant productivity A. Then,

$$y_{i,t} = Ak_{i,t-1}^{\alpha} \left(n_{i,t}^d\right)^{1-\alpha} - FC$$

where $k_{i,t-1}$ denotes the end-of-period demand for physical capital by intermediate firm i, $\alpha \in$ (0,1) is the capital share and $1 - \alpha$ is the labor share. FC $\geq$ 0 is a fixed cost of production, which it is imposed to ensure that intermediate firms' profits are zero in equilibrium. Zero profits guarantee a no free entry condition in the long-run. It is assumed that labor used by intermediate firm i $\in$ [0,1], $n_{i,t}^d$, is defined as a labor index given by the CES aggregator

$$n_{i,t}^d \equiv \left(\int_0^1 n_{j,i,t}^{\frac{\epsilon_w - 1}{\epsilon_w}} dj\right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{11}$$

where $n_{j,i,t}$ denotes the quantity of type j labor employed by intermediate firm i in period t. Intermediate firm's i problem is solved in two stages. In the first stage, intermediate firm i optimally decides how much labor of each type j to employ by minimizing its labor expenditures for any given employment level and for given nominal wage. Solving the problem for each intermediate firm i and then integrating across the different types of intermediate firms, gives the aggregate demand for labor of type j, described by eq. (3) in section 2.1. The second stage of intermediate firm's i problem is to minimize total nominal cost subject to the constraint of producing enough to meet demand.

As in Ascari (2004), Ascari & Sbordone (2014) and Yun (1986), a modified version of Calvo (1983) pricing setup is assumed. More specifically, in each period there is a fixed probability 1 $-\theta_p$ that an intermediate firm can re-optimize its nominal price. The optimal price set every period t is defined as $P^*_{i,t}$. With probability θ_p, instead, the intermediate firm automatically and without any cost adjusts its price according to an indexation rule that can depend both on the previous period inflation rate and/or on the steady state inflation rate, following the indexation rule: $P_{i,t+k} = P_{i,t}\left(\bar{\pi}^{\chi k}\right)^{1-\mu}\left(\pi^{\chi}_{t-k,t+k-1}\right)^{\mu}$. Parameter $\chi \in [0,1]$ allows for any degree of price indexation and $\mu \in [0,1]$ allows for any combination of indexation between steady state inflation $\bar{\pi}$ and past inflation rates. Intermediate firms discount profits k periods into the future by $\beta^k \frac{\lambda^n_{t+k}}{\lambda^n_t}\theta^k_p$, where $\beta^k \frac{\lambda^n_{t+k}}{\lambda^n_t}$ denotes the nominal stochastic discount factor which is taken as given by the intermediate firm and λ^n_{t+k} denotes the nominal valuation of income at period t+k, which is determined by the Lagrange multiplier from the household's problem. Solving the dynamic problem of an updating intermediate firm gives the optimal price setting equation

$$P^*_t = \frac{\epsilon_p}{\epsilon_p - 1}\frac{E_t\sum_{k=0}^{\infty}\theta^k_p\beta^k\lambda_{t+k}mc_{t+k|t}\left(\frac{\left(\bar{\pi}^{\chi k}\right)^{1-\mu}\left(\pi^{\chi}_{t-k,t+k-1}\right)^{\mu}}{P_{t+k}}\right)^{-\epsilon_p} y_{t+k}}{E_t\sum_{k=0}^{\infty}\theta^k_p\beta^k\lambda_{t+k}\left(\frac{\left(\bar{\pi}^{\chi k}\right)^{1-\mu}\left(\pi^{\chi}_{t-k,t+k-1}\right)^{\mu}}{P_{t+k}}\right)^{1-\epsilon_p} y_{t+k}} \tag{12}$$

where r^k_t is the real return on capital and mc_t denotes real marginal costs.

2.3 Capital Good Producers

Physical capital is produced by competitive capital good producers. The representative capital producer, buys period's t installed capital l_t and then uses the final good in the economy to add new investment x_t, so as to produce new installed capital l_{t+1} for period t+1. Afterwards, the new capital is sold to entrepreneurs. Capital production is assumed to be characterized by investment adjustment costs. Thus,

$$l_{t+1} = \left[1 - f\left(\frac{x_t}{x_{t-1}}\right)\right]x_t + l_t \tag{13}$$

where $f(\cdot)$ is an adjustment cost function with the following properties, $f(1) = f'(1) = 0$ and $f''(\cdot) > 0$. The representative capital producer maximizes his discounted real profits by choosing the optimal level of period t investment, x_t. Assuming that $f_t(\cdot) = \frac{\kappa}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2$, where κ is a parameter that determines investment adjustment cost; a first order condition which determines the relative price of capital q_t can be derived. Finally, the law of motion for aggregate capital is given by

$$k_t = (1-\delta)\,k_{t-1} + x_t - \frac{\kappa}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2 x_t \tag{14}$$

where k_{t-1} is the end-of-period aggregate capital stock and δ is a parameter that determines the quarterly depreciation rate of physical capital.

2.4 Entrepreneurs

As in Bernanke et al. (1999), entrepreneurs use their end of period real net worth N_t along with their nominal loans H_t to purchase new capital k_t

$$q_t k_t = N_t + \frac{H_t}{P_t} = N_t + h_t \tag{15}$$

where $h_t = \frac{H_t}{P_t}$ denotes real loans. Because the liabilities of entrepreneurs (or loans received by entrepreneurs) are expressed in nominal terms, a "Fisher effect" is possible. In this case, a rise in prices increases the net worth of entrepreneurs. A productivity shock ω_{t+1} is assumed to affect the capital purchased by entrepreneurs; where ω_{t+1} is log normally distributed with CDF $F(\omega_{t+1}, \sigma_\omega)$ and parameters μ_ω and σ_ω such that $E_t\{\omega_{t+1}\} = 1 \; \forall$ t. From the properties of the log-normal distribution, for any value of σ_ω it must hold that $E_t\{\omega_{t+1}\} = 1 \Rightarrow e^{\mu_\omega + \frac{1}{2}\sigma_\omega^2} = 1 \Rightarrow \mu_\omega = -\frac{1}{2}\sigma_\omega^2$.

The entrepreneur rents physical capital to intermediate goods producers who use it for production and pay a rental rate r_{t+1}^k. At the end of the period t, the entrepreneur sells the unappreciated capital to the capital producer at price q_{t+1}. Thus, the average return of the entrepreneur per nominal unit invested in period t is given by

$$1 + R_{t+1}^k = \frac{r_{t+1}^k + q_{t+1}(1-\delta)}{q_t}\pi_{t+1} \tag{16}$$

The debt contract is structured by assuming that for each state with associated return on physical capital R_{t+1}^k, entrepreneurs have to either pay a state contingent net nominal interest rate R_{t+1}^l on the loan, or choose to default. When an entrepreneur chooses to default, the financial intermediary acquires the entrepreneur's revenue, minus a portion μ^e that is lost in bankruptcy procedures. Therefore, the entrepreneur has an incentive to pay if he is able to do so. This happens when productivity is higher than the threshold $\overline{\omega}_{t+1}$ allowing the entrepreneur to pay back his debt,

$$\left(1 + R_{t+1}^l\right) H_t = \overline{\omega}_{t+1}\left(1 + R_{t+1}^k\right) P_t q_t k_t \tag{17}$$

Eq. (17) implies that given all the other variables, $\overline{\omega}_{t+1}$ and R_{t+1}^l move towards the same direction. The entrepreneur defaults if $\omega_{t+1} < \overline{\omega}_{t+1}$. In this case, the entrepreneur is being monitored by the financial intermediary, who gets a fraction $(1-\mu^e)$ of his revenues. The debt contract determines the value of

R^l_{t+1} in such a way that the zero profit condition of the financial intermediary is satisfied in all times,

$$[1 - F(\overline{\omega}_{t+1}, \sigma_\omega)] \left(1 + R^l_{t+1}\right) H_t + \\ (1 - \mu^e) \int_0^{\overline{\omega}_{t+1}} \omega dF(\omega, \sigma_\omega) \left(1 + R^k_{t+1}\right) P_t q_t k_t = (1 + i_t) H_t \quad (18)$$

The zero profit condition transfers all the aggregate risk of delivering the right level of return to the financial intermediary through changes in $\overline{\omega}_{t+1}$ along with the implied by these changes movements in R^l_{t+1}. Leverage is defined as the ratio of loans over entrepreneurial net worth. All entrepreneurs have the same leverage regardless of their level of net worth. Then, the problem of the entrepreneur is to choose the level of leverage ρ_t and a path for $\overline{\omega}_{t+1}$, so as to maximize its expected net worth given the zero profit condition of the financial intermediary.

Furthermore, as in Bernanke et al. (1999) it is assumed that at the end of each period a fraction γ^e_t of the entrepreneurs survives to the next period while the rest exit the economy and their capital holdings are transferred to households. Exiting entrepreneurs are then substituted by an equal number of new entrepreneurs that enter the economy with initial real net worth w^e. Following Villaverde (2010), it is assumed that γ^e_t follows an exogenous stochastic process that is defined in section 2.8. To simplify the algebra it is assumed that the surviving entrepreneurs, including those who went bankrupt during the period, also get the transfer w^e. Thus, and since all entrepreneurs also have the same leverage ρ_t, it follows that the net worth will be the same across all of them.

Finally, real net entrepreneurial transfers towards the household evolve as,

$$NT^r_t = (1 - \gamma^e_t) [1 - \Gamma(\bar{\omega}_t, \sigma_\omega)] \left[r^k_t + q_t (1 - \delta)\right] k_{t-1} - w^e \quad (19)$$

where the first term on the right hand side denotes the share of entrepreneurial profits that correspond to exiting entrepreneurs and are transferred to the household and w^e denotes funds that head from the household towards new and surviving entrepreneurs.

2.5 Financial Sector

As in Bernanke et al. (1999) the competitive financial sector is populated by financial firms that intermediate between households and entrepreneurs. The representative financial intermediary lends nominal funds H_t to entrepreneurs that pay the nominal return R^l_t. However, due to default and intermediation costs associated with lending, the financial intermediary can recover only the nominal interest rate i_t. Thus, the financial intermediary pays the nominal interest rate to households.

2.6 Government

The government collects lump sum taxes and issues government debt in order to finance real government spending $\bar{g}$ which is assumed to be constant. Given the government spending; debt and lump-sum taxes adjust so as the government budget constraint holds with equality. The government budget constraint, in real terms, is described by

$$\bar{g} = \tau_t^l + b_t - r_t^b b_{t-1} \tag{20}$$

2.7 Modeling Unemployment

Unemployment is modeled as in Galí (2011a), Galí (2011b) and Galí (2015a). The disutility from work for a household member of type (j,s), if being employed will be $\psi^n s^\phi$ and if not will be 0. All households are considered identical, in the sense that they contain all different member types. The representative household maximizes the whole household's welfare, so it would not find it optimal to send to work a household member (j,s) whose real wage is lower than his disutility from work because an action like this would result in welfare losses not only for the specific household member but for the whole household since full consumption sharing within the household is assumed. Thus, the representative household chooses to send to work workers of type (j,s) whose real wage is equal or higher than their individual disutility from work expressed into consumption units

$$\frac{W_{j,t}}{P_t} \geq \frac{\psi^n s^\phi}{\lambda_t} \tag{21}$$

Note that the left hand side of inequality (21) is the real wage of j^{th} labor type and its right hand denotes his marginal rate of substitution between leisure and consumption, $MRS_{j,t}$. If the labor market was competitive it would hold that

$$\frac{W_{j,t}}{P_t} = MRS_{j,t} = \frac{\psi^n L_{j,t}^\phi}{\lambda_t} \tag{22}$$

where $L_{j,t}$ denotes the total population of labor of type j in the economy[3]. In addition, $L_t = \int_0^1 L_{j,t} dj$ can be interpreted as a measure of aggregate participation or the labor force in the model. In the monop-

[3] $L_{j,t}$ denotes all household members of labor type j, either employed or unemployed.

olistically competitive labor market model, the number of employees is always lower[4] than the number of people in the labor force and the "gap" between them is determined by the wage mark-up. The unemployment rate u_t is defined as the ratio of the unemployed to the labor force. Finally, it is obvious that unemployment does not arise under a competitive labor market.

2.8 Monetary Policy and Exogenous Processes

Monetary policy is conducted by a monetary authority which sets the nominal interest rate according to a Taylor Rule that targets to stabilize inflation and the quarterly growth rate of real output while at the same time allows for interest rate smoothing

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\bar{i} + \Phi_\pi ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \Phi_y ln\left(\frac{y_t}{y_{t-1}}\right)\right] + \epsilon_{\upsilon,t} \tag{23}$$

where $\bar{\pi}$ is the long-run target for inflation, y_{t-1} is the period t-1 level of output, $\epsilon_{\upsilon,t} \overset{iid}{\sim} N(0,\sigma_\upsilon^2)$ is a monetary policy shock which follows a white noise process with zero mean and $\sigma_\upsilon \in (0,+\infty)$ standard deviation, $\bar{i}$ is the long-run nominal interest rate, $\rho_i \in [0,1]$ is a coefficient that determines the persistence of the nominal interest rate and Φ_π, Φ_y are policy response coefficients to inflation and the growth rate of real output, respectively.

The exogenous process $\{\gamma_t^e\}$ follows a logarithmic AR(1) process with drift

$$ln\left(\frac{\gamma_t^e}{\bar{\gamma}^e}\right) = \rho_\gamma ln\left(\frac{\gamma_{t-1}^e}{\bar{\gamma}^e}\right) + \epsilon_{\gamma,t} \tag{24}$$

where $\rho_\gamma \in [0,1)$ is the persistence parameter and $\bar{\gamma}^e \in [0,+\infty)$ denotes the long-run value of the exogenous variable. Moreover, $\epsilon_{\gamma,t} \overset{iid}{\sim} N(0,\sigma_\gamma^2)$ is a shock in the fraction of entrepreneurs that survive to the next period. The shock is assumed to follow a white noise process with zero mean and $\sigma_\gamma \in (0,+\infty)$ standard deviation.

2.9 Aggregate Resource Constraint

Market clearing requires

$$y_t = c_t + x_t + \bar{g} + \mu^e G(\bar{\omega}_t, \sigma_\omega)\left[r_t^k + q_t(1-\delta)\right]k_{t-1} \tag{25}$$

[4] Since the wage mark-up is greater than unity.

3 Quantitative Analysis

3.1 Calibration

A zero inflation steady state is assumed by setting the long-run inflation $\bar{\pi}$ equal to one. The long-run unemployment rate is set equal to the mean of the post Volcker period (1983Q1-2021Q1) unemployment rate series for the United States, which is 0.061. Then, keeping the value of elasticity ϕ constant and equal to 5 as in Galí (2011b), it is possible to calibrate the value of labor demand elasticity at the zero inflation steady state, $(1-0.061)^5 = \frac{\epsilon_w - 1}{\epsilon_w} \Rightarrow \epsilon_w \approx 3.7$.

Goods demand elasticity ϵ_p is set equal to 9, as in Galí (2011b). The rate of time preference parameter β is calibrated so as the long-run value of the annualized nominal interest rate to be equal to the mean of the federal funds rate series of the post Volcker period for the United States, for zero long-run inflation, $\bar{i}^{an} = \frac{\bar{\pi}^4 - \beta^4}{\beta^4} \Rightarrow 0.03796 = \frac{1^4 - \beta^4}{\beta^4} \Rightarrow \beta \approx 0.99$.

Then, the long-run value of the quarterly nominal interest rate is, $\bar{i} = \frac{1-0.99}{0.99} \approx 0.0101$. The quarterly rate of physical capital depreciation $\bar{\delta}$ is set equal to 0.025 as in Baxter & Farr (2005) and Gertler et al. (2007). In addition, it is assumed that the share of government spending on real output ω^g equals 37.9%, a value taken from the OECD database for the post Volcker period general government spending for the USA. Then, government spending is given by $\bar{g} = \omega^g y$, where y denotes the steady state of real output. The fixed cost of production FC is calibrated so as to guarantee that aggregate profits from all firms i are zero in equilibrium.

As far as the degree of hysteresis is concerned a relatively high value of 0.85 is chosen. Policy responses to output Φ_y and inflation Φ_π are set equal to the standard values of 0.5/4 and 1.5, respectively. In addition, a rather strong degree of monetary policy inertia, $\rho_i = 0.9$ is assumed. The persistence parameter of all AR(1) processes is set equal to 0.9 and an one percent standard deviation innovation for each exogenous process is assumed. Furthermore, relatively low degrees of price χ and wage $\widetilde{\chi}$ indexation 0.07 and 0.37, respectively are considered; whereas all indexation is to past prices and wages, meaning that $\mu = \widetilde{\mu} = 1$.

Next in line are the parameters that are specific to the costly state verification mechanism of the model. These are $prem$ or the premium between net return of entrepreneurial investment R^k and the risk free nominal interest rate $\bar{i}$; $\bar{F}$ which denotes the entrepreneur's probability of default; h_k or the long-run leverage to capital ratio; $\bar{\gamma}^e$ or the fraction of entrepreneurs that survives to the next period; σ_ω and μ_ω which are parameters of the log-normal CDF $F(\bar{\omega}, \sigma_\omega)$ distribution; w^e which denotes the initial net worth of entering entrepreneurs; and μ^e which determines the portion of the entrepreneurial revenue that is lost in bankruptcy procedures due to monitoring costs.

First, the steady state value of the premium is set equal to 25 basis points for quarterly data[5]. Then, $\bar{F}$ = 0.0056 as in Christiano et al. (2014); $\bar{\gamma}^e$ = 0.9728 as in Bernanke et al. (1999); and h_k = 1/3 as in Villaverde (2010). In addition, σ_ω, μ^e and the long-run value of $\bar{\omega}$ are jointly determined using numerical methods. Furthermore, thanks to the properties of the log-normal distribution, there is a relationship that connects parameters σ_ω and μ_ω. More specifically, $\mu_\omega = -\frac{1}{2}\sigma_\omega^2$. The value of w^e is calibrated using the equation that determines the net worth of entrepreneurs.

Standard values are assigned to the remaining non financial parameters[6]. The steady state level of employment from the Calvo wage setting model is used as a target for the union's long-run employment in the insiders-outsiders version of the model. In this case both models share the same steady state[7]. Finally, the model dynamics are derived by linearizing all relevant equations around the non stochastic zero inflation steady state and then using standard methods of numerical simulations.

3.2 The Effects of Labor Market Frictions on the Propagation of Aggregate Shocks

This section presents the transitional dynamics of the three models after a monetary shock and a financial shock. Figures 1 - 4 summarize the dynamic responses of key macroeconomic aggregates; expressed as percentage deviations from steady state. Each dynamic response is presented in comparison with the responses from the other two models. The size of the shock is normalized to 1 percent in both cases, while the sign is chosen so that unemployment increases on impact.

As far as the monetary policy rule is concerned, two variations of the Taylor rule are considered, both of them target to stabilize price inflation and either the output gap or the quarterly growth rate of real output. The output gap is defined as the deviation of real output from its natural (flexible prices and wages) level for every time period t. A numerical solution for the natural level of real output is applied. Woodford (2003) and Galí (2015b) among others, have shown that a policy rule that fully stabilizes the output gap provides an adequate approximation of optimal policy in standard DSGE models. Such a rule cannot be easily implemented in practice since the natural rate of output is not observed by the monetary authority. Nevertheless, it can provide a useful benchmark for optimal policy. Furthermore, note that under a flexible labor market, there are no wage mark-up fluctuations and thus, the unemployment rate does not respond to aggregate shocks.

[5]This corresponds to 100 basis points on an annual frequency.

[6]Tables 4 - 7 of appendix A.1, summarize all parameter values used for the numerical simulations.

[7]Table 8 of appendix A.2 reports this steady state.

3.2.1 A Taylor Rule that Stabilizes the Growth Rate of Output

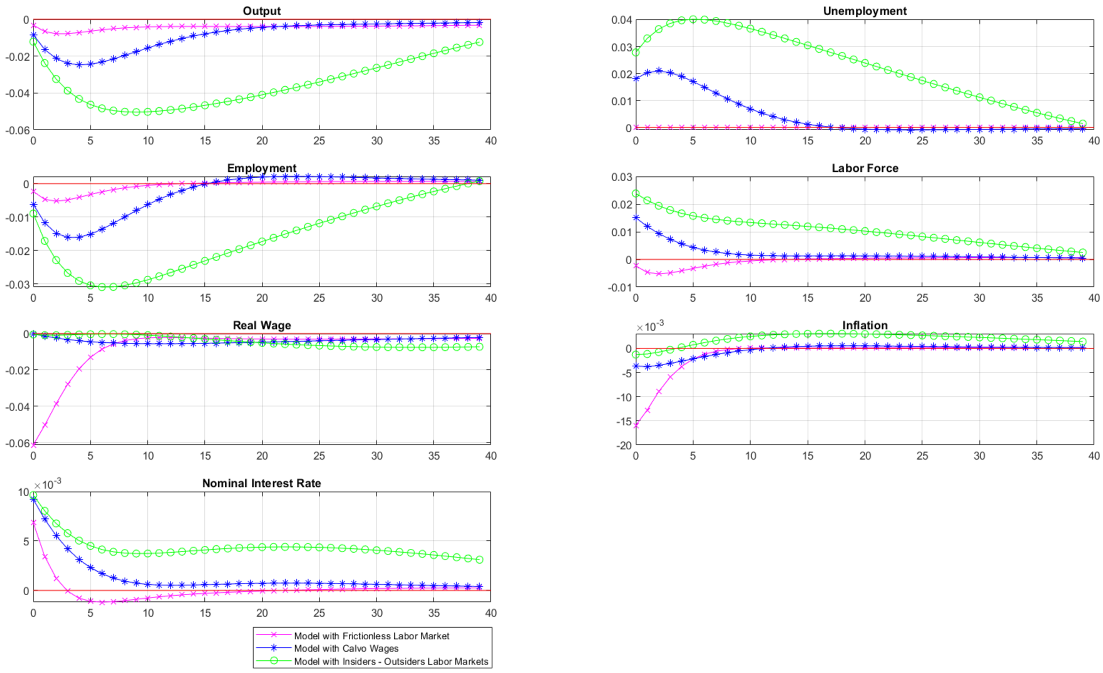
It is assumed that the monetary authority follows the Taylor rule described by eq. (23). Impulse response results indicate that hysteresis greatly amplifies the effects of the examined shocks relative to the other two labor market structures.

Monetary Policy Shock

From figures 1 and 2, one can see that after a contractionary monetary policy action, like an 1% unexpected increase in the nominal interest rate, employment, real output and inflation decrease on impact, whereas unemployment increases. Under the insiders-outsiders wage setting, the response of inflation quickly turns positive, this is attributed to the non responsiveness of nominal wages which causes inflationary pressures.

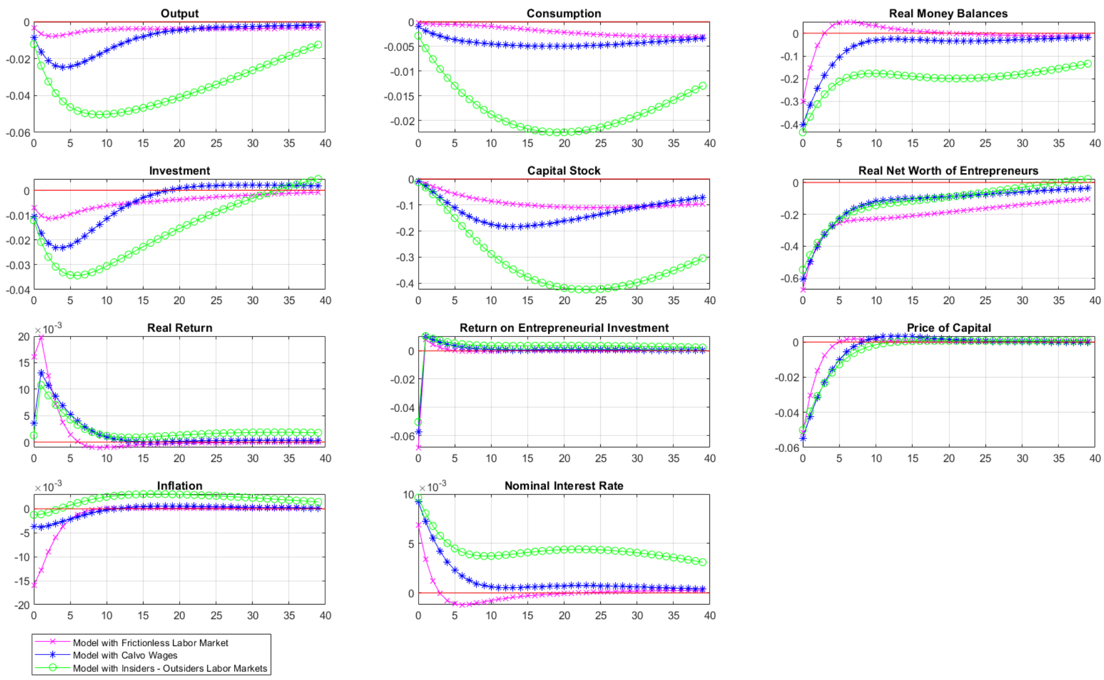
Due to the presence of financial frictions, a monetary policy shock leads to significant amplification for all aggregate macroeconomic variables. The enhanced amplification is attributed to the monetary policy that has a relatively large effect on investment and asset prices triggering by this way the "financial accelerator mechanism". In addition, inflation and price of capital both tend to decrease after a unexpected increase in nominal interest rates. This means that the financial accelerator and the "Fisher deflation" channels reinforce each other; amplifying by this way the negative impact of a contractionary monetary policy shock in the economy.

In the presence of hysteresis, the contraction in real output is 5 times stronger relative to the frictionless labor market case and 2.5 times stronger relative to the Calvo wages model.



% deviations from steady state, $\rho_i = 0.9$, $\sigma_\upsilon = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

Figure 1: Dynamic responses after a monetary policy shock.



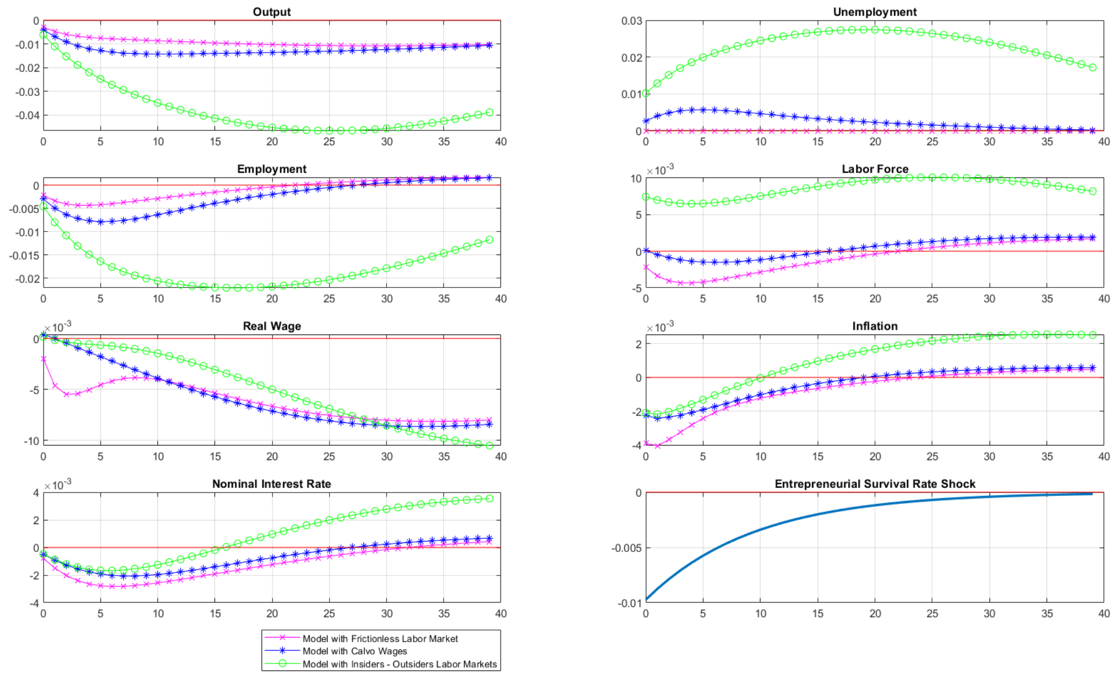
% deviations from steady state, $\rho_i = 0.9$, $\sigma_\upsilon = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

Figure 2: Dynamic responses after a monetary policy shock (cont.).

Entrepreneurial Survival Rate Shock

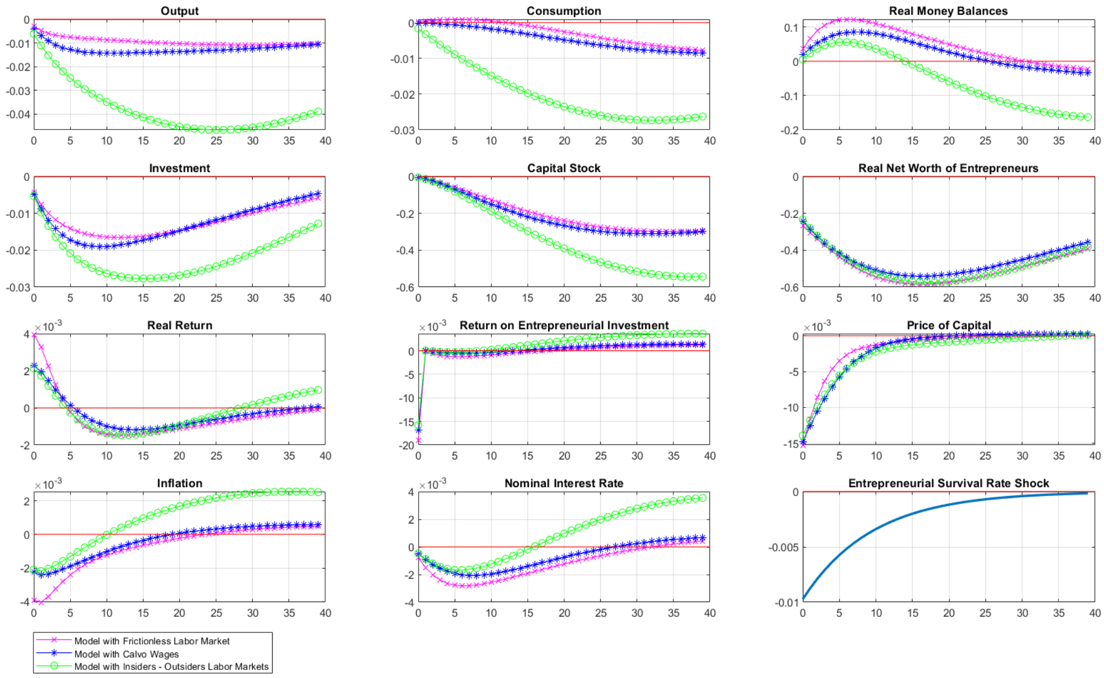
Figures 3 and 4 present the effects of an 1% unexpected decrease in the entrepreneurial survival rate. Essentially, a negative shock in the survival probability of entrepreneurs decreases the number of entrepreneurs that survive to the next period, causing employment and real output to decrease on impact and as a consequence the unemployment rate increases. Furthermore, inflation and real output drop on impact and the central bank decreases the nominal interest rate as a policy response. Moreover, in the hysteresis model, the recession is much stronger, around 5% in its peak relative to 1% in the frictionless labor market model and around 1.5% in the Calvo wages model. This causes a substantial increase in the unemployment rate.

Ina addition, the price of capital moves towards the same direction as inflation, meaning that the “financial accelerator mechanism” and the “Fisher deflation” channels reinforce each other as in the case of a monetary policy shock.



% deviations from steady state, $\rho_\gamma = 0.9$, $\sigma_\gamma = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

Figure 3: Dynamic responses after an unexpected decrease in the survival probability of entrepreneurs.



% deviations from steady state, $\rho_\gamma = 0.9$, $\sigma_\gamma = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

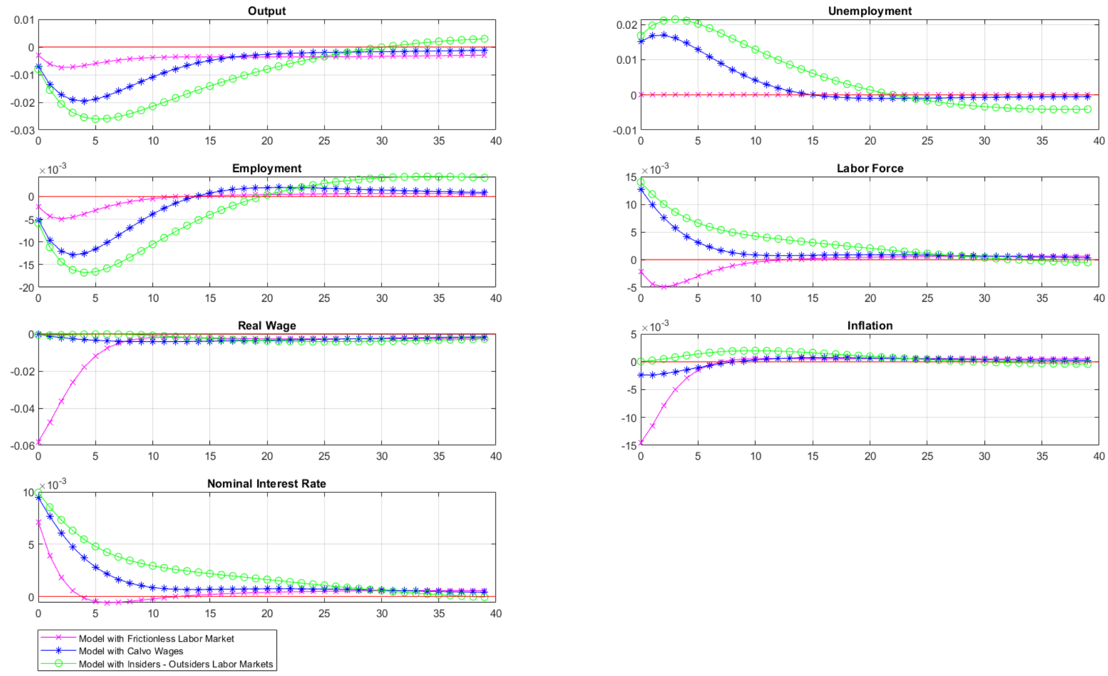
Figure 4: Dynamic responses after an unexpected decrease in the survival probability of entrepreneurs (cont.).

3.2.2 A Taylor Rule that Stabilizes the Output Gap

In this section, it is assumed that the monetary authority follows a Taylor rule that stabilizes the output gap (along with price inflation), according to

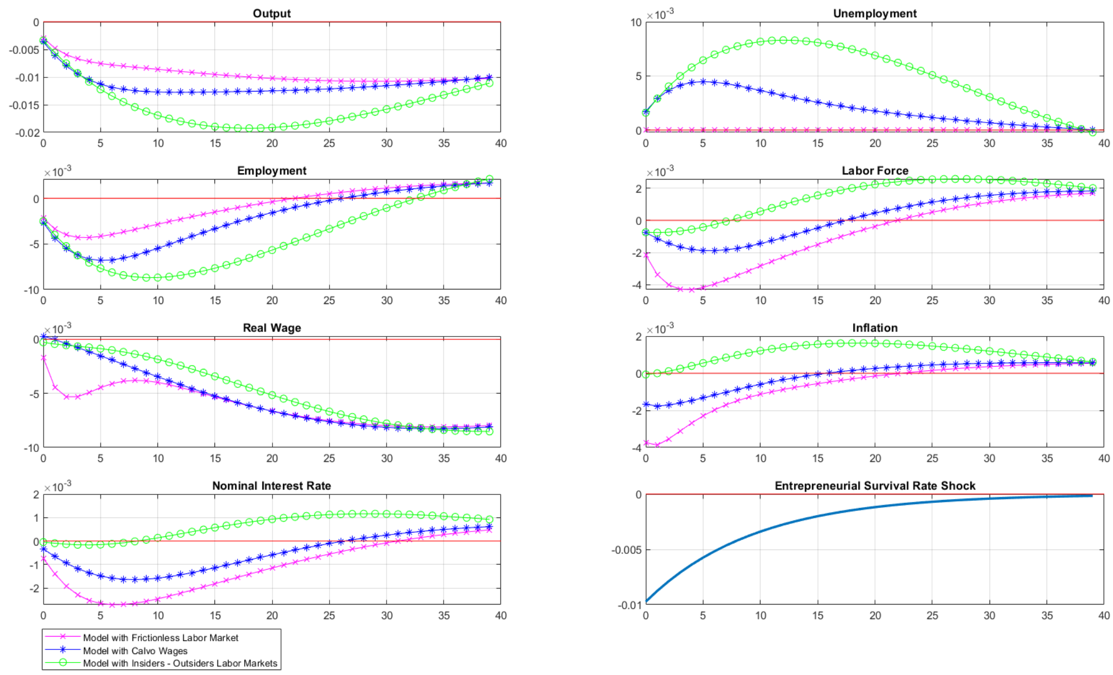
$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\bar{i} + \Phi_\pi ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \Phi_y ln\left(\frac{y_t}{y_t^f}\frac{y^f}{y}\right)\right] + \epsilon_{v,t}$$

where y_t^f denotes the flexible prices and wages real output and y, y^f denote the steady state values of output and flexible output, respectively. Figures 5 and 6 summarize the dynamic responses.



% deviations from steady state, $\rho_i = 0.9$, $\sigma_\upsilon = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

Figure 5: Dynamic responses after a monetary policy shock.



% deviations from steady state, $\rho_\gamma = 0.9$, $\sigma_\gamma = 0.01$. Policy response coefficients $\Phi_\pi = 1.5$, $\Phi_y = 0.5/4$.

Figure 6: Dynamic responses after an unexpected decrease in the survival probability of entrepreneurs.

One can observe that the dynamic responses from the frictionless labor market and Calvo wages models are almost identical to those presented in section 3.2.1. This means that the "simple" rule which stabilizes price inflation and the quarterly growth rate of output delivers the same business cycle dynamics as the output gap targeting rule. However, it is clear that this does not hold for the hysteresis model. In this case, the output gap targeting rule manages a better stabilization of the economy.

This is attributed to the fact that high hysteresis makes employment and consequently real output history dependent. Thus, a policy rule that targets the deviation of real output from its previous period value does not qualify as a good policy. In addition, high hysteresis implies higher nominal wage sluggishness which causes inflationary pressures that in turn mitigate the fall in the nominal interest rate. This in turn causes stronger and more prolonged drops in real output along with stronger and more persistent increases in the unemployment rate. However, a Taylor policy that instead targets the output gap achieves faster stabilization of real output and consequently employment and wage inflation.

As pointed out in Galí (2020), a Taylor rule that stabilizes price inflation and output growth fails to provide an anchor for unemployment or employment that would reduce the magnitude and persistence of the deviations of these variables from their optimal levels in response to aggregate shocks. Nevertheless, in this paper it is shown that a policy rule that targets to stabilize the output gap performs significantly better in terms of stabilizing these variables. The following sections concentrate on the welfare implications of the two rules.

4 Welfare Analysis

Welfare is defined as the present discounted value of the flow utility of the representative household. Then, the recursive representation of welfare can be expressed as

$$V_t = \mathbb{U}\left(c_t, n_{j,t}\right) + \beta E_t \left\{V_{t+1}\right\}$$

Welfare is computed for each model (frictionless labor market, Calvo wages and insiders-outsiders), by applying a second order approximation around the non stochastic steady state and calculating the approximated theoretical moments. Then, the expected (mean) values of welfare under different policy rules are compared. The units of welfare are expressed into differences in "consumption equivalent" units[8]. Assuming log preferences in consumption, it is possible to derive the following expression

$$\lambda^V = \exp\left(\left(1-\beta\right)\left[E\left\{V_t^F\right\} - E\left\{V_t^I\right\}\right]\right) - 1$$

[8]How much consumption would one be willing to give up (in each period) under one policy so as to enjoy the same level of welfare as under a different policy.

where λ^V denotes the fraction of consumption one would be willing to give up in each period in the baseline economy "I" to enjoy the same level of welfare as in the alternative economy "F"[9].

4.1 Taylor Rules

Tables 1 - 2, compare the welfare between the two versions of the Taylor rule. The benchmark is the Taylor rule that stabilizes price inflation along with the output gap. In the standard DSGE models, replicating the flexible equilibrium is the welfare-maximizing objective for monetary policy. Thus, minimization of output gaps characterizes well the optimal policy. More recent papers, such as Blanchard et al. (2015), Fatás & Summers (2018), Garga & Singh (2018), Moran & Queralto (2018) or Jordá & Singh & Taylor (2020) suggest that in models with hysteresis, optimal policy remains the same. However, such rule cannot be considered as "simple" rule, since the natural level of output cannot be observed in practice. It is calculated using numerical methods.

In the insiders-outsiders model welfare losses are normalized to be equal to zero under the output gap targeting Taylor rule and in the absence of hysteresis (γ = 0), for each shock. Moreover, it is assumed that the long-run employment target for the labor union is equal to the efficient level of employment[10]. Finally, since welfare results from the insiders - outsiders model depend on the degree of hysteresis, four different parameter values are considered, $\gamma = \{0, 0.5, 0.85, 0.99\}$.

	"Consumption Equivalent" Units Across Policies					
Policy	Frictionless Labor	Calvo Model	Ins - Out $\gamma = 0$	Ins - Out $\gamma = 0.5$	Ins - Out $\gamma = 0.85$	Ins - Out $\gamma = 0.99$
Taylor Rule (Output Gap)	0	0	0	0.0161	-0.0041	-0.0406
Taylor Rule (Growth Rate of Output)	-0.0240	-0.0619	-0.0619	-0.0437	-0.1744	-0.8543

A Taylor rule that stabilizes price inflation and the output gap, in the absence of hysteresis, is considered to be the baseline policy for each model.

Table 1: Taylor Rules, Monetary Policy Shock

[9] If the baseline economy "I" has higher welfare relative to economy "F", the term inside the exp is negative, which means that $\lambda^V < 0$. In other words, someone has to give up consumption in the high welfare economy "I".

[10] The long-run efficient level of employment is defined as the frictionless goods, labor and financial markets steady state employment, and is given by

$$n^e = \left\{ \left[\left(\frac{\alpha}{\left[\frac{1}{\beta} - (1-\delta)\right] q} \right)^{\alpha} A \right]^{\frac{1-\sigma}{1-\alpha}} \left(1 - \omega^g - \frac{\alpha\delta}{\left[\frac{1}{\beta} - (1-\delta)\right] q} \right)^{-\sigma} \frac{1-\alpha}{\psi^n} \frac{1-\beta b^c}{(1-b^c)^{\sigma}} \right\}^{\frac{1}{\phi+\sigma}}$$

	"Consumption Equivalent" Units Across Policies					
Policy	Frictionless Labor	Calvo Model	Ins - Out $\gamma = 0$	Ins - Out $\gamma = 0.5$	Ins - Out $\gamma = 0.85$	Ins - Out $\gamma = 0.99$
Taylor Rule (Output Gap)	0	0	0	0.0112	0.0134	0.0005
Taylor Rule (Growth Rate of Output)	-0.0006	-0.0114	-0.0159	-0.0030	-0.0654	-0.7839

A Taylor rule that stabilizes price inflation and the output gap, in the absence of hysteresis, is considered to be the baseline policy for each model.

Table 2: Taylor Rules, Entrepreneurial Survival Rate Shock

One interesting result is that after both shocks, the growth rate of output stabilization Taylor rule leads to heavy welfare losses. These losses increase with labor market frictions and with the degree of hysteresis. In particular, when hysteresis is close to unity, welfare losses relative to output gap targeting exceed 78%. The aforementioned result is attributed to the strong and persistent response of employment. As it was shown in section 3.2.1, both shocks destabilize employment due to the destabilization of wage inflation. Since, a Taylor rule that targets output growth performs poorly in terms of employment or wage inflation stabilization, welfare losses are significantly high. The next section examines the implications of wage inflation stabilization.

4.2 Hysteresis and Monetary Policy

Two monetary policy rules are considered. First, a rule that stabilizes price inflation, wage inflation and the output gap, according to

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\bar{i} + \Phi_\pi ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \Phi_y lnln\left(\frac{y_t}{y_t^f}\frac{y^f}{y}\right) + \Phi_w ln\left(\frac{w_t}{w_{t-1}}\frac{\pi_t}{\bar{\pi}}\right)\right] + \epsilon_{v,t} \tag{26}$$

Second, a rule that stabilizes price inflation, wage inflation and quarterly output growth, according to

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\bar{i} + \Phi_\pi ln\left(\frac{\pi_t}{\bar{\pi}}\right) + \Phi_y ln\left(\frac{y_t}{y_{t-1}}\right) + \Phi_w ln\left(\frac{w_t}{w_{t-1}}\frac{\pi_t}{\bar{\pi}}\right)\right] + \epsilon_{v,t} \tag{27}$$

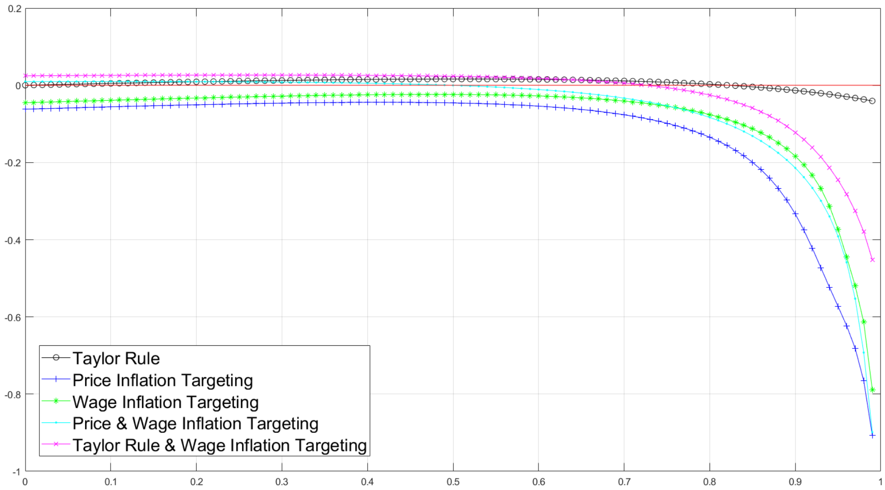
The following policy specifications are examined

Policy Rule	ρ_i	Φ_π	Φ_y	Φ_w
The standard Taylor rule	0.9	1.5	0.5/4	0
A price inflation targeting rule	0.9	1.5	0	0
A wage inflation targeting rule	0.9	0	0	1.5
A price & wage inflation targeting rule	0.9	1.5	0	1.5
Taylor rule & wage inflation targeting	0.9	1.5	0.5/4	1.5

Table 3: Policy Parameters

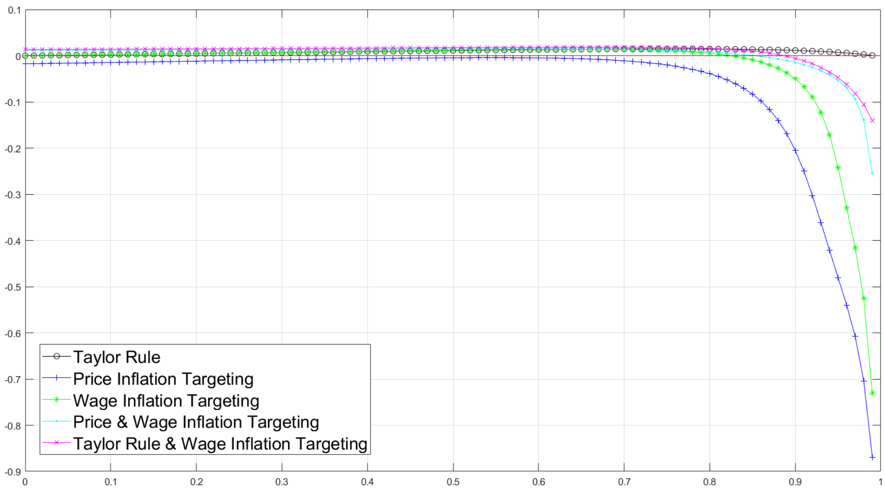
4.2.1 A Policy Rule that Stabilizes the Output Gap

In this section, it is assumed that the central bank follows the rule described by eq. (26). In each experiment, policy parameters are assigned the values reported in table 3. Results in terms of "consumption equivalent" units as a function of hysteresis are presented in figures 7 & 8. Welfare losses are normalized to be equal to zero under the Taylor rule and in the absence of hysteresis.



"Consumption equivalent" welfare losses across policies as a function of hysteresis (welfare losses are normalized to be equal to zero under the Taylor rule and in the absence of hysteresis).

Figure 7: Monetary policy shock (output gap targeting).



"Consumption equivalent" welfare losses across policies as a function of hysteresis (welfare losses are normalized to be equal to zero under the Taylor rule and in the absence of hysteresis).

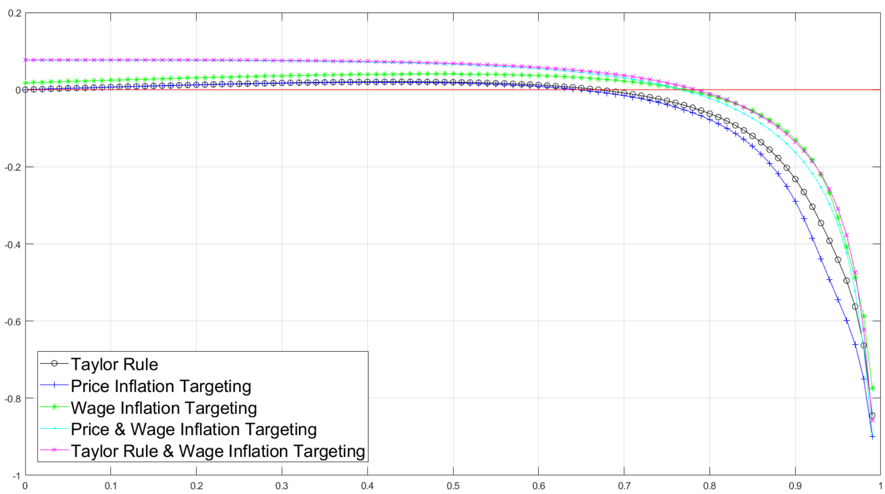
Figure 8: Unexpected decrease in the survival probability of entrepreneurs (output gap targeting).

From the figures above it is clear that, for low to average degrees of hysteresis, a policy rule that stabilizes price inflation, wage inflation and the output gap manages some welfare gains relative to the Taylor rule. However, when hysteresis takes values that are relatively high, the Taylor rule that stabilizes price inflation and the output gap achieves significantly higher welfare (or less losses) relative to rules that stabilize wage inflation or just the price inflation. This holds for both shocks.

In general, when there are more than one nominal rigidity in the model, then a policy rule that reacts to more targets works better (in terms of stabilization and welfare). Nevertheless, when hysteresis takes values that are close to one, employment and consequently real output are characterized by near unit root behavior due to the hysteresis equation. In this case, the cost of using the nominal interest rate to stabilize wage inflation (or equivalently employment) is extremely high. On the other hand, a Taylor policy that stabilizes the output gap achieves significantly higher welfare.

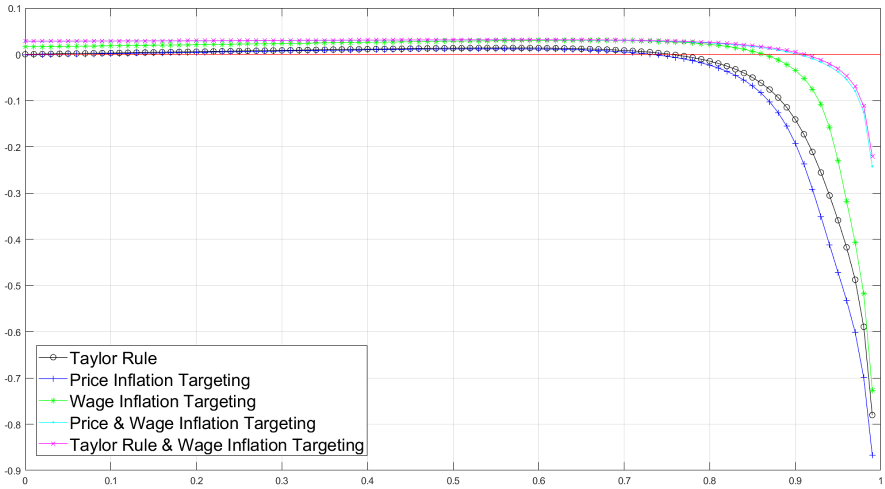
4.2.2 A Policy Rule that Stabilizes the Growth Rate of Output

In this section it is assumed that the monetary authority seeks to stabilize the quarterly growth rate of output according to eq. (27).



"Consumption equivalent" welfare losses across policies as a function of hysteresis (welfare losses are normalized to be equal to zero under the Taylor rule and in the absence of hysteresis).

Figure 9: Monetary policy shock (output growth targeting).



"Consumption equivalent" welfare losses across policies as a function of hysteresis (welfare losses are normalized to be equal to zero under the Taylor rule and in the absence of hysteresis).

Figure 10: Unexpected decrease in the survival probability of entrepreneurs (output growth targeting).

Figures 9 & 10, show that policy rules which stabilize price along with wage inflation achieve higher levels of welfare. The benefits from implementing such policies increase with the degree of hysteresis. This result is more evident after a financial shock.

As mentioned before, a Taylor rule that targets the growth rate of output fails to adequately stabilize employment (or wage inflation). In the insiders-outsiders model the nominal wage adjusts more sluggishly as hysteresis increases, as a result the persistence of employment increases. After aggregate shocks which cause a strong initial change in employment like a monetary policy shock or an entrepreneurial survival rate shock this effect is very strong. For high degrees of hysteresis a Taylor policy which also targets wage inflation manages a better stabilization of employment; something that the output growth targeting fails to accomplish. Thus, the more modest welfare losses.

5 Conclusions

Prompted by the fairly recent critique of dynamic stochastic general equilibrium models for their lack of a financial sector characterized by frictions, as well as for not being able to generate strong endogenous persistence for macroeconomic aggregates; this paper developed a medium-sized DSGE model that addresses these points of criticism. Overall, it is highlighted that a DSGE model that incorporates financial frictions along with hysteresis can mimic the effects of a severe financial crisis like the one of 2008-2009.

More specifically, quantitative results indicated that the presence of hysteresis greatly amplifies the effects of a monetary policy shock and a financial shock; both considered relevant to the onset of financial crises. This finding was stronger when the central bank followed a “simple” Taylor rule that stabilized price inflation and the growth rate of output. Nevertheless, when the central bank aimed to stabilize the output gap the responses of macroeconomic aggregates were milder although stronger and more persistent relative to the other two examined labor market structures.

In the standard monetary DSGE models, replicating the flexible (prices and wages) equilibrium is the welfare-maximizing objective for monetary policy. This study showed that a Taylor policy that stabilizes the output gap performs well, in terms of welfare, even in the presence of high hysteresis. This result is in line with recent papers, such as Blanchard et al. (2015), Fatás & Summers (2018), Garga & Singh (2018), Moran & Queralto (2018) or Jordá & Singh & Taylor (2020). In the presence of hysteresis, aggregate shocks will have highly persistent, although not permanent, impacts on the output gap. However, as pointed out in Cerra & Saxena (2000) the policy implications will be fairly similar with the case of full hysteresis.

Furthermore, the model addressed another point of criticism mentioned in the introduction. The “divine coincidence” does not hold in the hysteresis model. This was highlighted in section 4.2, where the price inflation stabilization delivered significantly less welfare in comparison with the Taylor rule.

Another crucial point is that the costs of inaction during recessions increase with the degree of hysteresis. For high degrees of hysteresis aggregate shocks can have permanent (or almost permanent) effects on the output gap through their interactions with the endogenous forces that drive the dynamics of labor markets. Thus, stabilization policy should try to offset the damaging impact of an adverse shock as soon as possible. Garga & Singh (2018) provide quantitative estimates of the benefits of monetary policy in the presence of hysteresis.

Finally, the present work showed that under high hysteresis, a policy that stabilizes the growth rate of output leads to heavy welfare losses relative to output gap targeting. In this case, a central bank can benefit from choosing to stabilize wage inflation. Galí (2020) finds similar results. More specifically, using a baseline New Keynesian model of hysteresis he shows that optimal monetary policy calls for a strong emphasis on employment or unemployment stabilization.

This last finding has direct policy implications. For instance, Galí (2020) suggests that a Taylor rule that stabilizes price inflation along with the growth rate of real output is a good approximation to ECB policy. Furthermore, Blanchard & Summers (1986), Clark & Summers (1982), Ellwood (1982), Cerra & Saxena (2000), Bluedorn & Leigh (2018) and Bluedorn & Leigh (2019) support that the European unemployment is characterized by a high degree of persistence. If this is the case, wage inflation targeting could help towards a faster stabilization of the European economy after a severe financial crisis.

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Appendices

A.1 Baseline Calibration

Calibration	
ω^g = 0.379	Share of government spending on real output
$\bar{F}$ = 0.0056	Entrepreneur's probability of default
$prem$ = 0.0025	Premium
h_k = 1/3	Leverage to capital ratio

Table 4: Parameters relevant only for steady state.

Calibration	
$\beta = 0.99$	Rate of time preference
$\sigma = 1$	Elasticity of intertemporal substitution
$\phi = 5$	Elasticity with which household members of type j enter or leave employment in response to shocks
$\alpha = 1/4$	Share of capital, then $(1-\alpha)$ is the labor share
$\bar{\pi} = 1$	Steady state level of quarterly inflation
$\epsilon_p = 9$	Goods demand elasticity
$\epsilon_w = 3.7$	Labor demand elasticity
$\theta_p = 0.75$	Calvo price adjustment
$\theta_w = 0.75$	Calvo wage adjustment
$\chi = 0.07$	Degree of price indexation
$\widetilde{\chi} = 0.38$	Degree of wage indexation
$b^c = 0.94$	Habit persistence parameter
$A = 1$	Total factor productivity
$\psi^n = 1$	Parameter related to disutility from work
δ = 0.025	Quarterly capital depreciation rate
$\bar{\gamma}^e$ = 0.9728	Fraction of surviving entrepreneurs
FC = 0.2126	Fixed cost of production
$\bar{g}$ = 0.6447	Level of government spending
σ_ω = 0.4014	Parameter of the log-normal CDF $F(\bar{\omega}_t, \sigma_\omega)$
μ_ω = -0.0805	Parameter of the log-normal CDF $F(\bar{\omega}_t, \sigma_\omega)$
μ^e = 0.4129	Monitoring costs of bankrupt entrepreneurs
w^e = 0.1111	Initial net worth of entering entrepreneurs
$\bar{i}$ = 0.0101	Long-run value of the nominal interest rate

Table 5: Parameters relevant for both steady state and dynamic equilibria.

Calibration	
$\Phi_y = 0.5/4$	Policy response to real output
$\Phi_\pi = 1.5$	Policy response to inflation
$\kappa = 4.05$	Investment adjustment cost parameter
$\mu = 1$	Distribution of price indexation between past and steady state inflation
$\widetilde{\mu} = 1$	Distribution of wage indexation between past and steady state inflation
$\rho_i = 0.9$	Degree of monetary policy inertia
$\rho_\gamma = 0.9$	Persistence of entrepreneurial survival rate shock
σ_υ = 0.01	Standard deviation of monetary policy shock
σ_γ = 0.01	Standard deviation of entrepreneurial survival rate shock

Table 6: Parameters relevant only for the dynamic equilibrium.

Calibration	
γ = 0.85	Degree of hysteresis
n^* = 1.0585	Union's long run employment target

Table 7: Parameters relevant to the insiders-outsiders model.

A.2 Steady State Results

Variable		Steady State Value
Real Output	y	1.7012
Consumption	c	0.7658
Employment	n	1.0585
Labor Force	L	1.1273
Real Wage	w	1.2053
Inflation	π	1
Optimal Real Wage	$\widetilde{w}$	1.2053
Unemployment Rate	u	0.0610
Capital Stock	k	11.3106
Investment	x	0.2828
Net Worth of Entrepreneurs	N	7.5404
Productivity Bankruptcy Threshold	$\bar{\omega}$	0.3334
Return of Entrepreneurial Investment	R^k	0.0126
Real Amount of Loans	h	3.7702
Price of Capital	q	1
Price Dispersion	Δ^p	1
Wage Dispersion	Δ^w	1
Dispersion of Labor Types	Δ^L	1
Nominal Interest Rate	i	0.0101
Real Rental Return of Capital	r^k	0.0376
Real Marginal Costs	mc	0.8889
Wage Mark-up	μ^w	1.3698

Table 8: Steady state results of the Calvo and insiders-outsiders models.

Variable		Steady State Value
Real Output	y	1.7928
Consumption	c	0.8071
Employment	n	1.1155
Labor Force	L	1.1155
Real Wage	w	1.2053
Inflation	π	1
Unemployment Rate	u	0
Capital Stock	k	11.9197
Investment	x	0.2980
Net Worth of Entrepreneurs	N	7.9465
Productivity Bankruptcy Threshold	$\bar{\omega}$	0.3334
Return of Entrepreneurial Investment	R^k	0.0126
Real Amount of Loans	h	3.9732
Price of Capital	q	1
Price Dispersion	Δ^p	1
Nominal Interest Rate	i	0.0101
Real Rental Return of Capital	r^k	0.0376
Real Marginal Costs	mc	0.8889
Wage Mark-up	μ^w	1

Table 9: Steady state results of the frictionless labor market model.

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