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Abstract

We analyze the relation between the level of the inflation target and the zero lower bound (ZLB) imposed on the nominal interest rate. We analyze this relation in the framework of a behavioral macroeconomic model in which agents experience cognitive limitations. The model produces endogenous waves of optimism and pessimism (animal spirits) that, because of their self-fulfilling nature, drive the business cycle and in turn are influenced by the business cycle. We find that when the inflation target is too close to zero, the economy can get gripped by “chronic pessimism” that leads to a dominance of negative output gaps and recessions, and in turn feeds back on expectations producing long waves of pessimism. The simulations of our model, using parameter calibrations that are generally found in the literature, suggests that an inflation target of 2% is too low, i.e. produces negative skewness in the distribution of the output gap. We find that an inflation target in the range of 3% to 4% comes closer to producing a symmetric distribution of the output gap and avoids the economy being trapped in a region of chronic pessimism.

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1. Introduction

An inflation target too close to zero risks pushing the economy into a negative inflation territory even when mild shocks occur. Such an outcome is generally considered to be dangerous. Economists have identified several risks associated with negative inflation. Two of these have received much attention in the economic literature. First, during periods of deflation the nominal interest rate is likely to hit the lower zero bound. When this happens the real interest rate cannot decline further. In fact when deflation intensifies, the real interest rate increases, further aggravating the deflationary dynamics. In such a scenario the central bank loses its capacity to stimulate the economy in a recession, thereby risking prolonged recessions (Eggertson and Woodford(2003), Aruoba, & Schorfheide, F. (2013), Blanchard, et al. (2010), Ball(2014)).

Second, deflation raises the real value of debt leading to attempts of agents to reduce their debt by saving more. This adds to the deflationary dynamics. This debt deflation dynamics was first described by Fisher(1933) and has received renewed attention since the financial crisis of 2007-08 (see Koo(2011), Eggertsson and Krugman(2012)).

In this paper we focus on the first risk. Standard linear DSGE models have tended to underestimate the probability of hitting the ZLB as was shown by Chung, et al., (2012). Most of these models have led to the prediction that when the central bank keeps an inflation target of 2%, it is very unlikely for the economy to be pushed into the ZLB (Reifschneider and Williams (2000), Coenen(2003), Schmitt-Grohe and Uribe(2007),). We use a behavioral macroeconomic model to shed new light on the nature of this risk. This model is characterized by the fact that agents experience cognitive limitations preventing them from having rational expectations. It is a model that produces endogenous waves of optimism and pessimism (animal spirits) that drive the business cycle (De Grauwe(2012), and De Grauwe and Ji(2016)). We will show that the level at which the central banks sets the inflation target affects these animal spirits in a profound way. The latter become a propagation mechanism that can push the economy more often into the ZRB that commonly predicted by standard DSGE-models.

The paper is organized as follows. Section 2 presents the model and its main characteristics. Sections 3 to 5 present the results of this model, and section 6 contains the conclusion.

2. The behavioral model

The model consists of an aggregate demand equation, an aggregate supply equation and a Taylor rule.

The aggregate demand equation is specified in the standard way:

$$y_t = a_1 \tilde{E}_t y_{t+1} + (1 - a_1) y_{t-1} + a_2 (r_t - \tilde{E}_t \pi_{t+1}) + \varepsilon_t \qquad (1)$$

where y_t is the output gap in period t, r_t is the nominal interest rate, π_t is the rate of inflation, and ε_t is a white noise disturbance term. The tilde above E refers to the fact that expectations are not formed rationally. How exactly these expectations are formed will be specified subsequently.

We follow the procedure introduced in New Keynesian DSGE-models of adding a lagged output in the demand equation. This can be justified by invoking inertia in decision making. It takes time for agents to adjust to new signals because there is habit formation or because of institutional constraints. For example, contracts cannot be renegotiated instantaneously.

The aggregate supply equation is derived from profit maximization of individual producers. As in DSGE-models, a Calvo pricing rule and some indexation rule used in adjusting prices is assumed. This leads to a lagged inflation variable in the equation[1]. The supply curve can also be interpreted as a New Keynesian Philips curve:

$$\pi_t = b_1 \tilde{E}_t \pi_{t+1} + (1 - b_1) \pi_{t-1} + b_2 y_t + \eta_t \qquad (2)$$

Finally the Taylor rule describes the behavior of the central bank

[1] It is now standard in DSGE-models to use a pricing equation in which marginal costs enter on the right hand side. Such an equation is derived from profit maximisation in a world of imperfect competition. It can be shown that under certain conditions the aggregate supply equation (2) is equivalent to such a pricing equation (see Gali(2008), Smets and Wouters(2003)).

$$r_t = c_1(\pi_t - \pi^*) + c_2 y_t + c_3 r_{t-1} + u_t \tag{3}$$

where π^* is the inflation target; The central bank is assumed to smooth the interest rate. This smoothing behavior is represented by the lagged interest rate in equation (3).

Introducing heuristics in forecasting output

Agents are assumed to use simple rules (heuristics) to forecast the future output and inflation. The way we proceed is as follows. We assume two types of forecasting rules. A first rule can be called a "fundamentalist" one. Agents estimate the steady state value of the output gap (which is normalized at 0) and use this to forecast the future output gap[2]. A second forecasting rule is an "extrapolative" one. This is a rule that does not presuppose that agents know the steady state output gap. They are agnostic about it. Instead, they extrapolate the previous observed output gap into the future. The two rules are specified as follows:

The fundamentalist rule is defined by $\widetilde{E}_t^f y_{t+1} = 0$ (4)

The extrapolative rule is defined by $\widetilde{E}_t^e y_{t+1} = y_{t-1}$ (5)

This kind of simple heuristic has often been used in the behavioral finance literature where agents are assumed to use fundamentalist and chartist rules (see Brock and Hommes(1997), Branch and Evans(2006), De Grauwe and Grimaldi(2006)). It is probably the simplest possible assumption one can make about how agents who experience cognitive limitations, use rules that embody limited knowledge to guide their behavior. They only require agents to use information they understand, and do not require them to understand the whole picture.

Thus the specification of the heuristics in (4) and (5) should not be interpreted as a realistic representation of how agents forecast. Rather is it a parsimonious representation of a world where agents do not know the "Truth" (i.e. the underlying model). The use of simple rules does not mean that the agents are

[2] In De Grauwe(2012) more complex rules are used, e.g. it is assumed that agents do not know the steady state output gap with certainty and only have biased estimates of it.

dumb and that they do not want to learn from their errors. We will specify a learning mechanism later in this section in which these agents continuously try to correct for their errors by switching from one rule to the other.

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

$$\widetilde{E}_t y_{t+1} = \alpha_{f,t} \widetilde{E}_t^f y_{t+1} + \alpha_{c,t} \widetilde{E}_t^e \tag{6}$$

$$\widetilde{E}_t y_{t+1} = \alpha_{f,t} 0 + \alpha_{c,t} y_{t-1} \tag{7}$$

$$\text{and} \quad \alpha_{f,t} + \alpha_{e,t} = 1 \tag{8}$$

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

A methodological issue arises here. The forecasting rules (heuristics) introduced here are not derived at the micro level and then aggregated. Instead, they are imposed ex post, on the demand and supply equations. This has also been the approach in the learning literature pioneered by Evans and Honkapohja(2001). Ideally one would like to derive the heuristics from the micro-level in an environment in which agents experience cognitive problems. Our knowledge about how to model this behavior at the micro level and how to aggregate it is too sketchy, however. Psychologists and brains scientists struggle to understand how our brain processes information. There is as yet no generally accepted model we could use to model the micro-foundations of information processing in a world in which agents experience cognitive limitations. We have not tried to do so[3].

Selecting the forecasting rules in forecasting output

As indicated earlier, agents in our model are willing to learn, i.e. they continuously evaluate their forecast performance. This willingness to learn and to change one's behavior is the most fundamental definition of rational behavior. Thus our agents in the model are rational, not in the sense of having rational expectations. We have rejected the latter because it is an implausible assumption

[3] There are some attempts to provide micro-foundations of models with agents experiencing cognitive limitations, though. See e.g. Kirman, (1992), Delli Gatti, et al.(2005).

to make about the capacity of individuals to understand the world. Instead our agents are rational in the sense that they learn from their mistakes. The concept of “bounded rationality” is often used to characterize this behavior.

The first step in the analysis then consists in defining a criterion of success. This will be the forecast performance of a particular rule. Thus in this first step, agents compute the forecast performance of the two different forecasting rules as follows:

$$U_{f,t} = -\sum_{k=0}^{\infty} \omega_k \left[y_{t-k-1} - \tilde{E}_{f,t-k-2} y_{t-k-1} \right]^2 \tag{9}$$

$$U_{e,t} = -\sum_{k=0}^{\infty} \omega_k \left[y_{t-k-1} - \tilde{E}_{e,t-k-2} y_{t-k-1} \right]^2 \tag{10}$$

where $U_{f,t}$ and $U_{e,t}$ are the forecast performances (utilities) of the fundamentalist and extrapolating rules, respectively. These are defined as the mean squared forecasting errors (MSFEs) of the forecasting rules; ω_k are geometrically declining weights. We make these weights declining because we assume that agents tend to forget. Put differently, they give a lower weight to errors made far in the past as compared to errors made recently. The degree of forgetting will turn out to play a major role in our model.

The next step consists in evaluating these forecast performances (utilities). We apply discrete choice theory (see Anderson, de Palma, and Thisse, (1992) and Brock & Hommes(1997)) in specifying the procedure agents follow in this evaluation process. If agents were purely rational they would just compare $U_{f,t}$ and $U_{e,t}$ in (9) and (10) and choose the rule that produces the highest value. Thus under pure rationality, agents would choose the fundamentalist rule if $U_{f,t} > U_{e,t}$, and vice versa. However, things are not so simple. Psychologists have found out that when we have to choose among alternatives we are also influenced by our state of mind. The latter is to a large extent unpredictable. It can be influenced by many things, the weather, recent emotional experiences, etc. One way to formalize this is that the utilities of the two alternatives have a deterministic component (these are $U_{f,t}$ and $U_{e,t}$ in (9) and (10)) and a random component $\varepsilon_{f,t}$ and $\varepsilon_{e,t}$ The probability of choosing the fundamentalist rule is then given by

$$\alpha_{f,t} = P\left[U_{f,t} + \varepsilon_{f,t} > (U_{e,t} + \varepsilon_{e,t} \right] \tag{11}$$

In words, this means that the probability of selecting the fundamentalist rule is equal to the probability that the stochastic utility associated with using the fundamentalist rule exceeds the stochastic utility of using an extrapolative rule. In order to derive a more precise expression one has to specify the distribution of the random variables $\varepsilon_{f,t}$ and $\varepsilon_{e,t}$. It is customary in the discrete choice literature to assume that these random variables are logistically distributed (see Anderson, Palma, and Thisse(1992), p.35). One then obtains the following expressions for the probability of choosing the fundamentalist rule:

$$\alpha_{f,t} = \frac{exp(\gamma U_{f,t})}{exp(\gamma U_{f,t}) + exp(\gamma U_{e,t})} \qquad (12)$$

Similarly the probability that an agent will use the extrapolative forecasting rule is given by:

$$\alpha_{e,t} = \frac{exp(\gamma U_{e,t})}{exp(\gamma U_{f,t}) + exp(\gamma U_{e,t})} = 1 - \alpha_{f,t} \qquad (13)$$

Equation (12) says that as the past forecast performance of the fundamentalist rule improves relative to that of the extrapolative rule, agents are more likely to select the fundamentalist rule for their forecasts of the output gap. Equation (13) has a similar interpretation. The parameter γ measures the “intensity of choice”. It is related to the variance of the random components $\varepsilon_{f,t}$ and $\varepsilon_{e,t}$. If the variance is very high, γ approaches *0.* In that case agents decide to be fundamentalist or extrapolator by tossing a coin and the probability to be fundamentalist (or extrapolator) is exactly 0.5. When $\gamma = \infty$ the variance of the random components is zero (utility is then fully deterministic) and the probability of using a fundamentalist rule is either 1 or 0. The parameter γ can also be interpreted as expressing a willingness to learn from past performance. When $\gamma = 0$ this willingness is zero; it increases with the size of γ.

As argued earlier, the selection mechanism used should be interpreted as a learning mechanism based on “trial and error”. When observing that the rule they use performs less well than the alternative rule, agents are willing to switch to the more performing rule. Put differently, agents avoid making systematic mistakes by constantly being willing to learn from past mistakes and to change their behavior. This also ensures that the market forecasts are unbiased.

Heuristics and selection mechanism in forecasting inflation

Agents also have to forecast inflation. A similar simple heuristics is used as in the case of output gap forecasting, with one rule that could be called a fundamentalist rule and the other an extrapolative rule. (See Brazier et al. (2006) for a similar setup). We assume an institutional set-up in which the central bank announces an explicit inflation target. The fundamentalist rule then is based on this announced inflation target, i.e. agents using this rule have confidence in the credibility of this rule and use it to forecast inflation. Agents who do not trust the announced inflation target use the extrapolative rule, which consists in extrapolating inflation from the past into the future.

The fundamentalist rule will be called an "inflation targeting" rule. It consists in using the central bank's inflation target to forecast future inflation, i.e.

$$\widetilde{E}_t^{tar} = \pi^* \tag{14}$$

where the inflation target is π^*

The "extrapolators" are defined by

$$E_t^{ext}\pi_{t+1} = \pi_{t-1} \tag{15}$$

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

$$\widetilde{E}_t\pi_{t+1} = \beta_{tar,t}\widetilde{E}_t^{tar}\pi_{t+1} + \beta_{ext,t}\widetilde{E}_t^{ext}\pi_{t+1} \tag{16}$$

or

$$\widetilde{E}_t\pi_{t+1} = \beta_{tar,t}\pi^* + \beta_{ext,t}\pi_{t-1} \tag{17}$$

$$\text{and } \beta_{tar,t} + \beta_{ext,t} = 1 \tag{18}$$

The same selection mechanism is used as in the case of output forecasting to determine the probabilities of agents trusting the inflation target and those who do not trust it and revert to extrapolation of past inflation, i.e.

$$\beta_{tar,t} = \frac{\exp(\gamma U_{tar,t})}{\exp(\gamma U_{tar,t}) + \exp(\gamma U_{ext,t})} \quad (19)$$

$$\beta_{ext,t} = \frac{\exp(\gamma U_{ext,t})}{\exp(\gamma U_{tar,t}) + \exp(\gamma U_{ext,t})} \quad (20)$$

where $U_{tar,t}$ and $U_{ext,t}$ are the forecast performances (utilities) associated with the use of the fundamentalist and extrapolative rules. These are defined in the same way as in (9) and (10), i.e. they are the negatives of the weighted averages of past squared forecast errors of using fundamentalist (inflation targeting) and extrapolative rules, respectively

This inflation forecasting heuristics can be interpreted as a procedure of agents to find out how credible the central bank's inflation targeting is. If this is very credible, using the announced inflation target will produce good forecasts and as a result, the probability that agents will rely on the inflation target will be high. If on the other hand the inflation target does not produce good forecasts (compared to a simple extrapolation rule) the probability that agents will use it will be small.

Defining animal spirits

The forecasts made by extrapolators and fundamentalists play an important role in the model. In order to highlight this role we define an index of market sentiments, which we call "animal spirits", and which reflects how optimistic or pessimistic these forecasts are.

The definition of animal spirits is as follows:

$$S_t = \begin{cases} \alpha_{e,t} - \alpha_{f,t} & if\ y_{t-1} > 0 \\ -\alpha_{e,t} + \alpha_{f,t} & if\ y_{t-1} < 0 \end{cases} \quad (21)$$

where S_t is the index of animal spirits. This can change between -1 and +1. There are two possibilities:

- When $y_{t-1} > 0$, extrapolators forecast a positive output gap. The fraction of agents who make such a positive forecasts is $\alpha_{e,t}$. Fundamentalists, however, then make a pessimistic forecast since they expect the positive output gap to decline towards the equilibrium value of 0. The fraction of agents who make such a forecast is $\alpha_{f,t}$. We subtract this fraction of pessimistic forecasts from the fraction $\alpha_{e,t}$ who make a positive forecast. When these two fractions are equal to each other (both are then 0.5) market sentiments (animal spirits) are neutral, i.e. optimists and pessimists cancel out and S_t = *0*. When the fraction of optimists $\alpha_{e,t}$ exceeds the fraction of pessimists $\alpha_{f,t}$, S_t becomes positive. As we will see, the model allows for the possibility that $\alpha_{e,t}$ moves to 1. In that case there are only optimists and $S_t = 1$.

- When $y_{t-1} < 0$, extrapolators forecast a negative output gap. The fraction of agents who make such a negative forecasts is $\alpha_{e,t}$. We give this fraction a negative sign. Fundamentalists, however, then make an optimistic forecast since they expect the negative output gap to increase towards the equilibrium value of 0. The fraction of agents who make such a forecast is $\alpha_{f,t}$. We give this fraction of optimistic forecasts a positive sign. When these two fractions are equal to each other (both are then 0.5) market sentiments (animal spirits) are neutral, i.e. optimists and pessimists cancel out and S_t = *0*. When the fraction of pessimists$\alpha_{e,t}$ exceeds the fraction of optimists $\alpha_{f,t}$ S_t becomes negative. The fraction of pessimists, $\alpha_{e,t}$, can move to 1. In that case there are only pessimists and S_t = *-1*.

We can rewrite (21) as follows[4]:

$$S_t = \begin{cases} \alpha_{e,t} - (1 - \alpha_{e,t}) = 2\,\alpha_{e,t} - 1 & if\ y_{t-1} > 0 \\ -\alpha_{e,t} + (1 - \alpha_{e,t}) = -2\,\alpha_{e,t} + 1 & if\ y_{t-1} < 0 \end{cases} \qquad (22)$$

Solving the model

The solution of the model is found by first substituting (3) into (1) and rewriting in matrix notation. This yields:

[4] In De Grauwe(2012) animal spirits are defined so as to move between 0 and 1. It can be shown that the animal sprits defined here are the same apart from a linear transformation that allows the animal sprits index to move between -1 and +1.

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

Or

$$\boldsymbol{A}\boldsymbol{Z_t} = \boldsymbol{B}\widetilde{\boldsymbol{E_t}}\,\boldsymbol{Z_{t+1}} + \boldsymbol{C}\boldsymbol{Z_{t-1}} + \boldsymbol{b}r_{t-1} + \boldsymbol{v_t} \tag{23}$$

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

$$\boldsymbol{Z_t} = \boldsymbol{A}^{-\boldsymbol{1}}\left[\boldsymbol{B}\widetilde{\boldsymbol{E_t}}\,\boldsymbol{Z_{t+1}} + \boldsymbol{C}\boldsymbol{Z_{t-1}} + \boldsymbol{b}r_{t-1} + \boldsymbol{v_t}\right] \tag{24}$$

The solution exists if the matrix $\boldsymbol{A}$ is non-singular, i.e. if $(1-a_2c_2)-a_2b_2c_1 \neq 0$. The system (24) describes the solution for y_t and π_t given the forecasts of y_t and π_t . The latter have been specified in equations (4) to (12) and can be substituted into (24). Finally, the solution for r_t is found by substituting y_t and π_t obtained from (24) into (3).

The model has non-linear features making it difficult to arrive at analytical solutions. That is why we will use numerical methods to analyze its dynamics. In order to do so, we have to calibrate the model, i.e. to select numerical values for the parameters of the model. In appendix the parameters used in the calibration exercise are presented. The model was calibrated in such a way that the time units can be considered to be quarters. The three shocks (demand shocks, supply shocks and interest rate shocks) are independently and identically distributed (i.i.d.) with standard deviations of 0.5%.

3. Inflation targeting and the zero lower bound

In this section we present the results of simulating the model for different values of the inflation target (going from 0% to 4%), and imposing a zero lower bound (ZLB) on the nominal interest rate:

$$\mathrm{r}_t \geq 0 \tag{25}$$

Without the ZLB condition, the central bank is able to adjust its nominal interest rate to achieve a real interest rate that stabilizes the output gap. However, with the ZLB condition, the ability of the central bank to stabilize the output gap (especially a negative one) is very much hindered. It depends on how much the level of real interest rate $(r_t - \widetilde{E_t}\pi_{t+1})$ in the demand equation (1) adjusts. As suggested earlier, the real interest rate is related to the inflation target π^*as shown in equation (17).

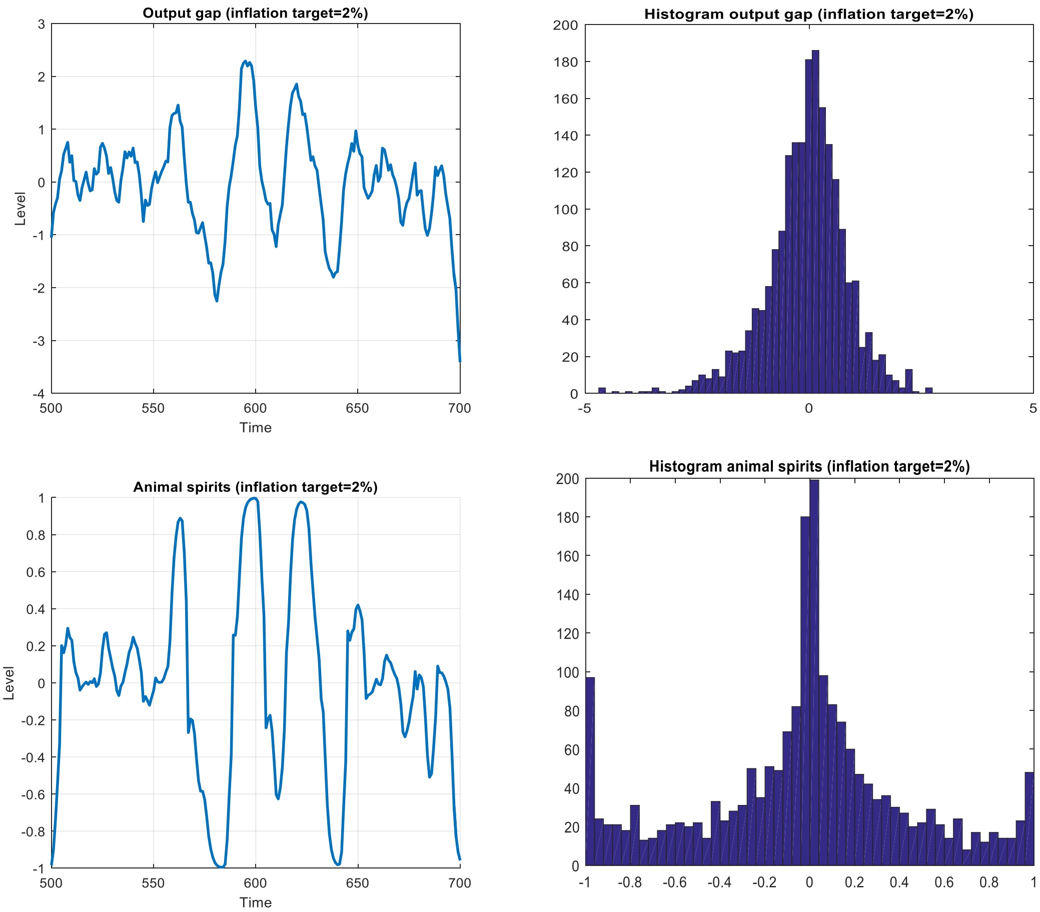
We start by presenting the results using an inflation target of 2%. This will allow us to understand the main features of the model. We then present the results for alternative levels of the inflation target.

Figure 1 shows the movements of the output gap and animal spirits in the time domain (left hand side panels) and in the frequency domain (right hand side panels) as simulated in our model. We observe that the model produces waves of optimism and pessimism (animal spirits) that can lead to a situation where everybody becomes optimist (S_t = 1) or pessimist (S_t = -1). These waves of optimism and pessimism are generated endogenously and arise because optimistic (pessimistic) forecasts are self-fulfilling and therefore attract more agents into being optimists (pessimists).

As can be seen from the left hand side panels, the correlation of these animal spirits and the output gap is high. In the simulations reported in figure 1 this correlation reaches 0.94. Underlying this correlation is the self-fulfilling nature of expectations. When a wave of optimism is set in motion, this leads to an increase in aggregate demand (see equation 1). This increase in aggregate demand leads to a situation in which those who have made optimistic forecasts are vindicated. This attracts more agents using optimistic forecasts. This leads to a self-fulfilling dynamics in which most agents become optimists. It is a dynamics that leads to a correlation of the same beliefs. The reverse is also true. A wave of pessimistic forecasts can set in motion a self-fulfilling dynamics leading to a downturn in economic activity (output gap). At some point most of the agents have become pessimists.

The right hand side panels show the frequency distribution of output gap and animal spirits. We find that the output gap is not normally distributed, with excess kurtosis and fat tails. A Jarque-Bera test rejects normality of the distribution of the output gap. The origin of the non-normality of the distribution of the output gap can be found in the distribution of the animal spirits. We find that there is a concentration of observations of animal spirits around 0. This means that most of the time there is no clear-cut optimism or pessimism. We can call these "normal periods". There is also, however, a concentration of extreme values at either -1 (extreme pessimism) and +1 (extreme optimism). These extreme values of animal spirits explain the fat tails observed in the distribution of the output gap. The interpretation of this result is as follows. When the market is gripped by a self-fulfilling movement of optimism (or pessimism) this can lead to a situation where everybody becomes optimist (pessimist). This then also leads to an intense boom (bust) in economic activity.

Figure 1: Output gap and animal spirits in time and frequency domains
(Inflation target = 2%)



In De Grauwe(2012) and De Grauwe and Ji(2016) empirical evidence is provided indicating that observed output gaps in industrial countries exhibit non-normality and that the output gaps are highly correlated with empirical measures of animal spirits. Our model mimics these empirical observations and is particularly suited to understand the nature of business cycle which is characterized by periods of "tranquility" alternated by periods of booms and busts.

We now ask the question of how these results are affected by the level of the inflation target chosen by the central bank. We start by noting that the output gap in Figure 1 is slightly skewed to the left. In fact the skewness is found to be about -0.66. This skewness finds its origin in the fact that the distribution of animal spirits is also skewed to the left, i.e. there are more periods of pessimism than optimism. We find that on average animal spirits are negative (-0.03).

In order to evaluate the importance of the inflation target we simulated the model under two alternative and extreme assumptions of the inflation targets. In the first one we set the inflation target equal to 0%; in the second one to 4%. We show the results in Figures 2 and 3.

Our major findings are the following. We observe from Figure 2 that when the inflation target is zero we obtain a very skewed distribution of output gap and animal spirits (skewness is -0.96 and mean animal spirits is -0.22). Most of the time animal spirits are negative with many periods of extreme pessimism. There are very few periods of optimism. This can also be seen from the simulations in the time domain: the output gap is negative most of the time and animal spirits are also negative most of the time. Thus it can be concluded when the central bank sets an inflation target equal to zero pessimism prevails most of the time and recession is a chronic feature of the business cycle with very few periods of optimism and optimism.

Things are very different with an inflation target of 4%. The results are presented in Figure 3. We now find that the distribution output gap and animal spirits is symmetric. Skewness of output gap is not statistically different from 0 and animal spirits are 0 on average. Periods of optimism and pessimism occur equally frequently.

Figure 2: Output gap and animal spirits in time and frequency domains
(Inflation target = 0%)

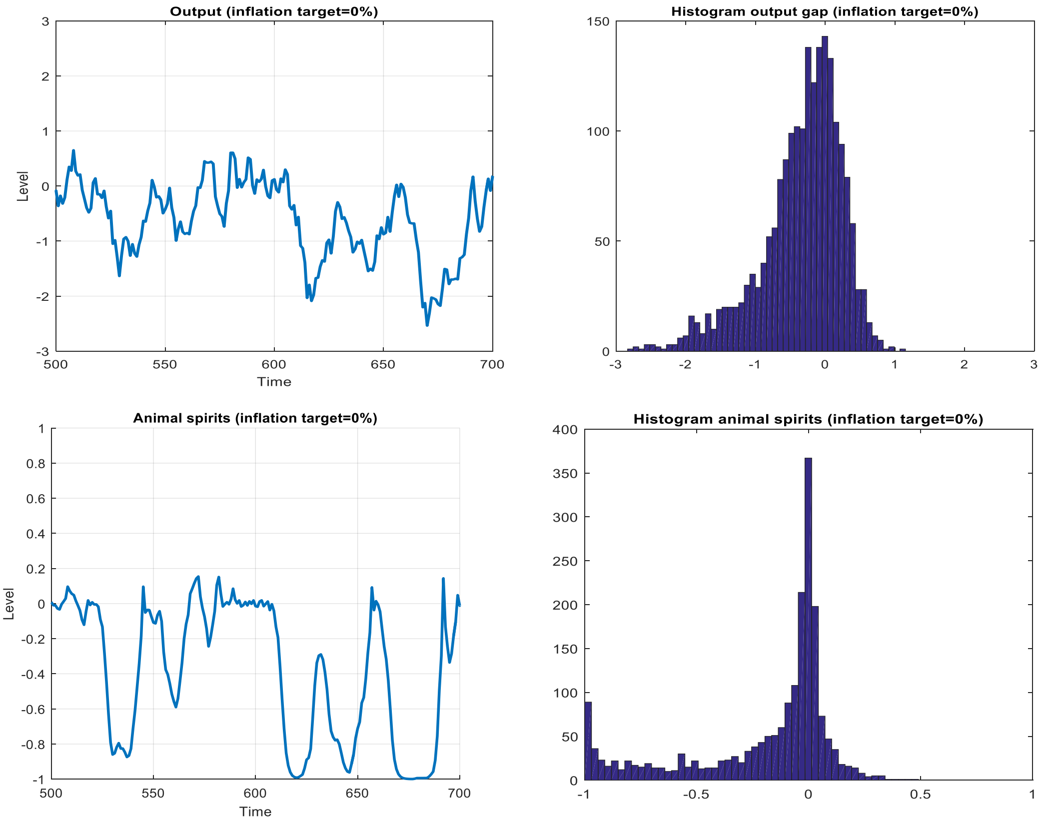
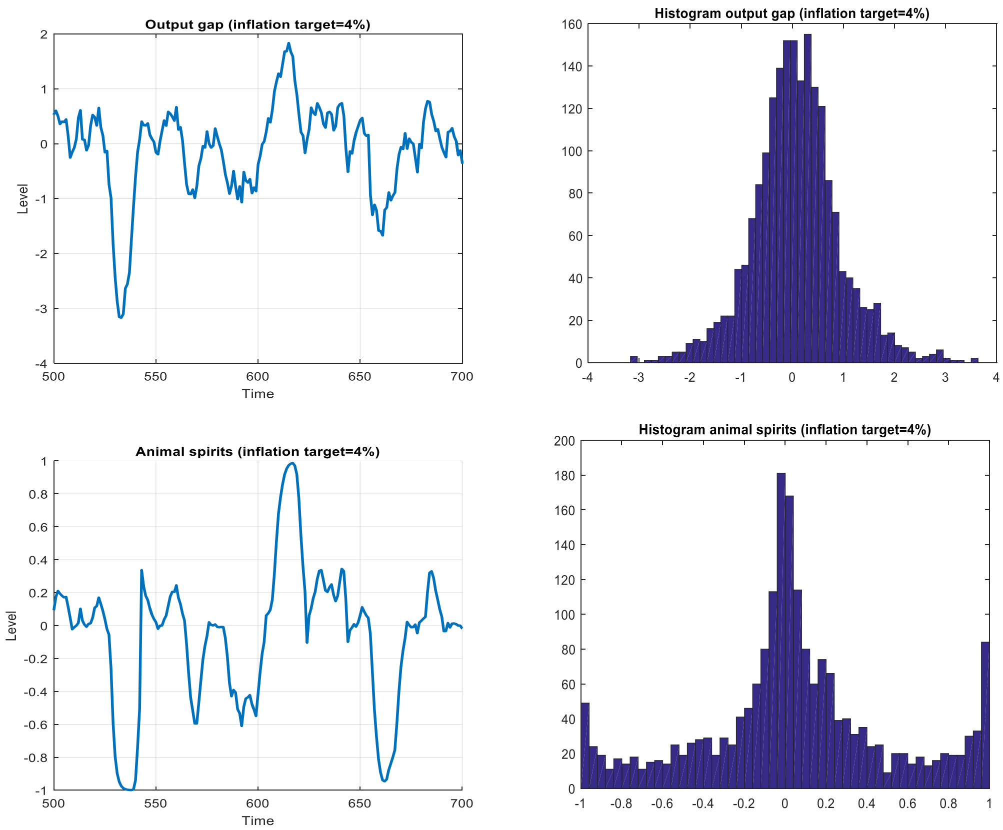


Figure 3: Output gap and animal spirits in time and frequency domains
(Inflation target = 4%)



In order to obtain a more precise idea about the relation between inflation target and the asymmetry in the distribution of output gap and animal spirits we computed the skewness of the distribution of output gap and the mean animal spirits for different values of the level of the inflation target. We show the results in Figures 4 and 5. From Figure 4 we conclude that as the inflation target increases the skewness of the distribution of the output gap declines. It reaches values close to 0 when the inflation target is 3%. We note the non-linear relation between inflation target and skewness. With an inflation target equal to 2% skewness is reduced substantially but there is still a significant amount of skewness, suggesting that an inflation target of 2% may not be optimal. We return to the question of optimality in the next section.

Figure 5 shows the relation between inflation target and the mean animal spirits. We find that when the inflation target increases the mean value of animal spirits increases in a non-linear way. Put differently with increasing inflation target (starting from 0%) endemic pessimism is reduced significantly. When the inflation target reaches 3% animal spirits are zero on average, i.e. periods of optimism and pessimism are equally probable.

Figure 4:

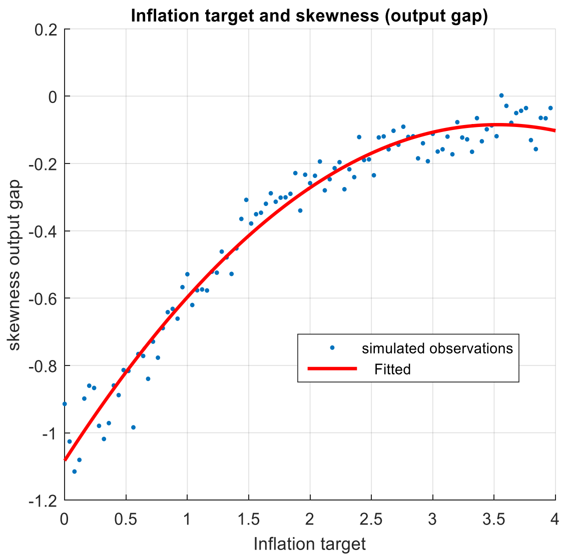
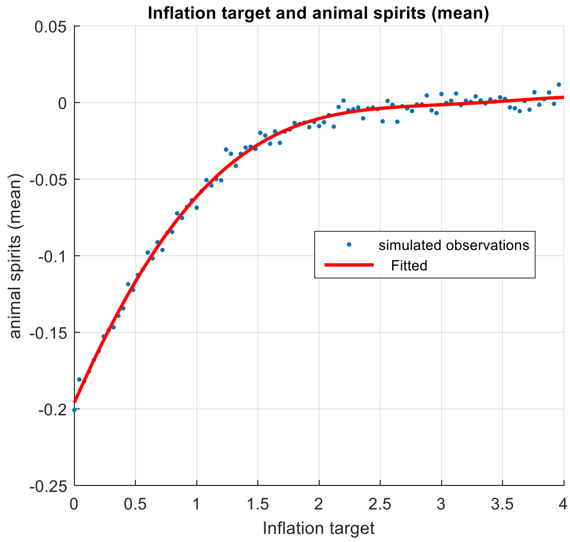


Figure 5



How can these results be interpreted? When the inflation target is 0% the cyclical movements in output gap and animal spirits inevitably lead to recessions that also drive inflation into negative territory. When that happens the zero bound constraint that applies to the nominal interest rates makes it impossible for the central bank to lower the real interest rate. If the recession is deep and deflation intense the real interest rate is likely to increase significantly. Thus the recession becomes protracted. Pessimism sets in and amplifies the recession, deflation and validates pessimism. As the central bank loses its stabilizing capacity the economy gets stuck in pessimism, recession and deflation. We conclude that an inflation target of 0% becomes a breeding ground for pessimism and recession. The way out is to increase the inflation target. Such an increase has a very strong initial effect and quickly pulls the economy out of the chronic pessimism trap. Our results suggest that an inflation target of 3% is probably better than 2% in making sure that the economy does not get stuck in the chronic pessimism trap.

4. Optimality of monetary policies and the zero bound constraint

We analyze the optimality of monetary policy by constructing tradeoffs between inflation and output variability in the different inflation targeting regimes. We start by computing the variability of the output gap and inflation when the central bank increases its output stabilization effort. The latter is measured by the output coefficient, c_2, in the Taylor rule. We show the results in figures 6 and 7. Figure 6 plots the standard deviation of the output gap for increasing values of the Taylor output parameter. We obtain the conventional result that by increasing the Taylor output parameter the central bank reduces the variability of the output gap.

Our results become unconventional in Figure 7. This plots the variability of inflation for increasing values of the Taylor output parameter. We now find that when this parameter is low (there is very little output stabilization) increasing it leads to a reduction of the variability of inflation. Only when the Taylor output parameter is large enough (larger than 0.5) we obtain the conventional result that more output stabilization comes at a price in the form of more inflation variability (see De Grauwe(2012) for more explanation).

This non-linearity comes from animal spirits. When output stabilization is very low, animal spirits are very strong leading to strong booms and bust features. These not only lead to a lot of output volatility but also tend to destabilize inflation. Thus a central bank gains both in terms of less output and inflation variability by stabilizing output. Businessmen would say this is a "win-win" situation. This "win-win" situation is limited however. Too much output stabilization will at some point lead to increasing inflation volatility as it undermines the central bank's inflation credibility. At that point (in our simulations when the Taylor output parameter exceeds 0.5) more stabilization leads to more inflation volatility.

Figures 6 and 7 allow us to construct the tradeoffs between output and inflation variability. This is done in Figure 8. It has a non-linear feature, which can be explained as follows. When the central bank does not stabilize output (Taylor output parameter is then 0) we are located on the upper right extreme on the tradeoff. By increasing this parameter we move downward along the positively sloped leg of the tradeoff. This means that more stabilization leads to less variability in both output and inflation. A "win-win"-situation. At some critical point we reach the minimum point of the tradeoff. More stabilization then implies an upward movement along the negatively sloped leg of the tradeoff. This is when we reach the proper tradeoff, i.e. more stabilization leads to a decline in output variability at the expense of more inflation variability.

Figure 6: Output variability and Taylor output parameter

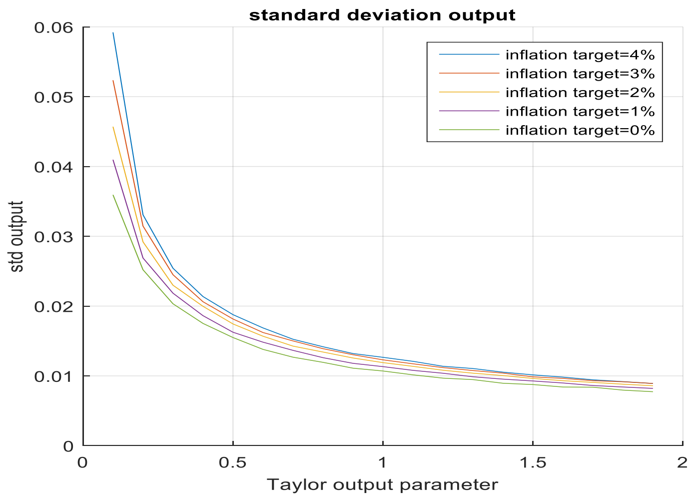


Figure 7: Inflation variability and Taylor output parameter

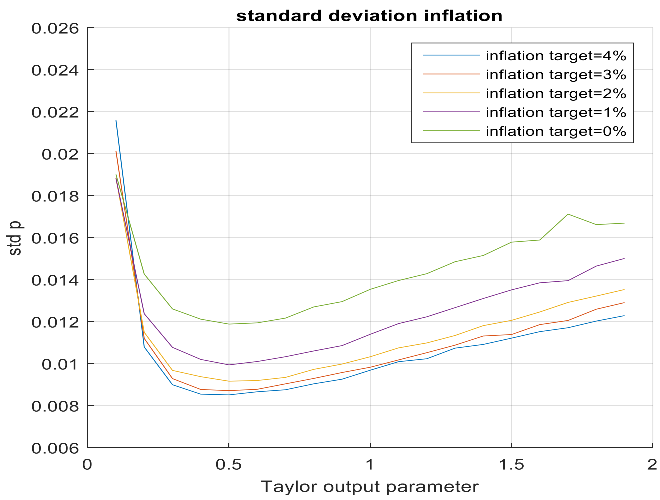
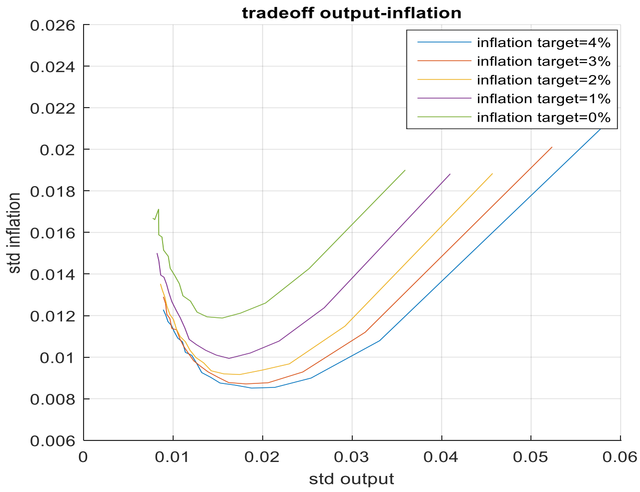


Figure 8 allows us to draw some conclusions about the optimality of inflation targeting. We observe that when the inflation target increases from 0% to 4% the tradeoff shifts downwards, i.e. the central bank improves the tradeoff by raising the inflation target. Note that these improvements become smaller as the inflation target is raised. Going beyond 4% does not improve the tradeoff in a significant way anymore.

Figure 8



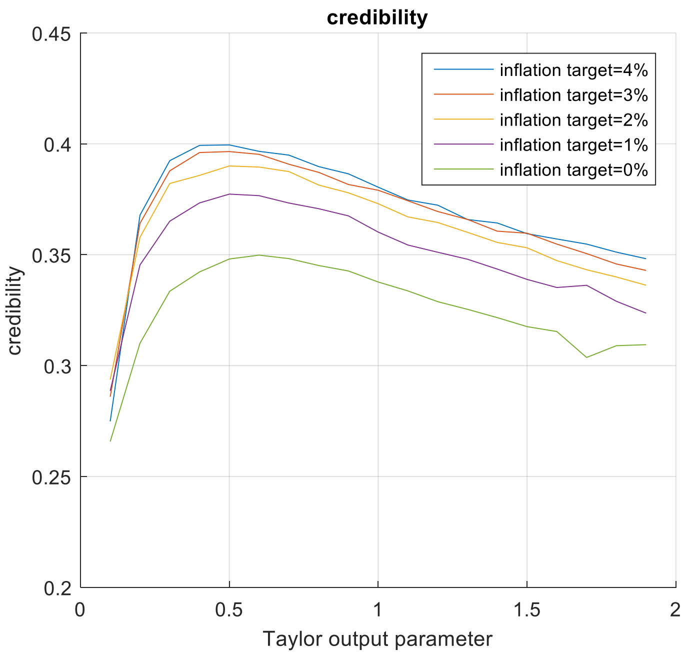
5. Credibility of inflation targeting and the zero lower bound

Our model allows us to give a precise definition of the credibility of the inflation target. This can be defined by the fraction of agents who use the announced inflation target as their forecast for future inflation. We have called these agents the "targeters". Since these agents use the announced inflation target as their inflation forecast it can be said that they trust the central bank's inflation commitment. In contrast, the extrapolators do not trust the central bank.

We used this insight to compute an index of inflation credibility, which we define to be the fraction of "targeters". We then computed this index for different values of the Taylor output parameter and the inflation target. We show the result in Figure 9. Two results stand out. First, when the central bank increases its stabilization effort (the Taylor parameter increases) this has the effect of first increasing the inflation credibility of the central bank. When the Taylor output parameter reaches a value of approximately 0.5 further stabilization efforts lead to a decline in inflation credibility.

Second, an increase in the inflation target has the effect of shifting the credibility lines upwards, i.e. when the central bank increases its inflation target from 0% to 4% its credibility in fighting inflation increases for all values of the Taylor output parameter. Put differently, by the increasing inflation target the central bank improves its inflation credibility whether she applies little or much output stabilization.

Figure 9: Credibility and inflation targets



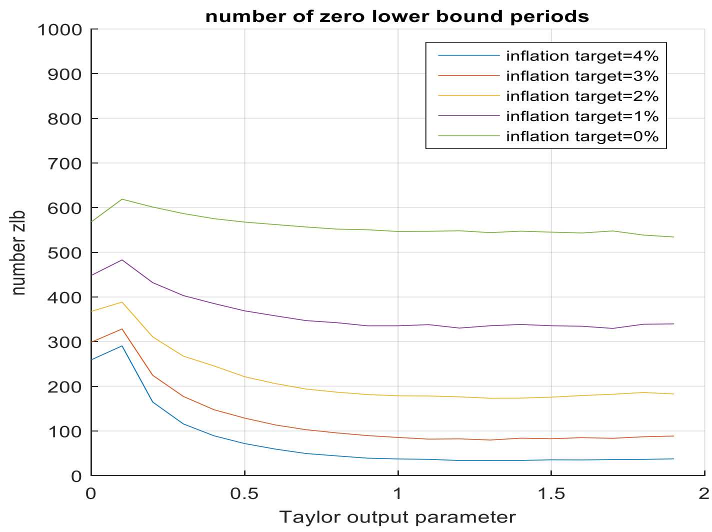
These results can be given the following interpretation. First, when the central bank increases its stabilization efforts, this has at first a positive effect on the credibility of its inflation target. The reason is, as was discussed earlier, that by stabilizing output the central bank also reduces the amplitude of the waves of optimism and pessimism (animal spirits) thereby stabilizing not only output but also inflation. This increases its inflation credibility. This positive effect on credibility disappears when the Taylor output parameter reaches 0.5. It can be seen that there is a relation between the tradeoff and credibility. From Figure 7 we observe that when the Taylor output parameter is close to 0.5 the variability of inflation is minimized. This is the underlying reason why inflation credibility is maximized for a Taylor output parameter that is close to 0.5. Note that the empirical literature reveals that central banks tend to set the Taylor output parameter close to 0.5

Second, when the inflation target is set too low, the rate of inflation is more likely to be pushed into negative territory. This is the territory in which the central bank loses its capacity to influence both inflation and output by varying the interest rate. As result, it will frequently fail to reach its inflation target. By raising the inflation target it reduces the frequency of hitting the zero lower bound. As a result, it maintains its capacity to affect inflation and output by varying the interest rate.

We show the relation between the number of periods the economy hits the zero lower bound on the one hand, and the Taylor output parameter and the inflation target on the other hand, in Figure 10. On the vertical assets we show the number of periods when the zero bound constraint applies (out of a total of 1000 periods). We find that with an inflation target of 0% we hit the zero lower bound more than half of the time. As the inflation target declines this number is reduced substantially. Note the importance of the Taylor output parameter. When this parameter is close to zero, i.e. the central bank does not do much output stabilization the number of times we hit the zero bound is quite large, even with high inflation targets. By increasing output stabilization the central banks reduces the probability of hitting the zero bound constraint. This result has to do with something we observed earlier. When the central bank does not stabilize output the amplitude in the waves of optimism and pessimism is high leading to strong boom and bust features in the economy. These are more likely to push the economy into negative inflation territory at some point in time.

Note that we find that if the central bank keeps the Taylor output parameter close to 0.5 and maintains an inflation target of 2% the probability of hitting the ZLB is about 20%. With inflation targets of 3% and 4% this probability is lowered to about 10%. The probabilities of hitting the ZLB that are generate in our model are higher than the standard linear DSGE models could do.

Figure 10: Number of ZLB periods, stabilization and inflation targets



6. Conclusion

In this paper we have analyzed the relation between the level of the inflation target and the zero lower bound constraint imposed on the nominal interest rate. We analyzed this relation in the framework of a behavioral macroeconomic model in which agents experience cognitive limitations. This forces them to use simple rules of thumb to forecast the output gap and the rate of inflation. The model produces endogenous waves of optimism and pessimism (animal spirits) that, because of their self-fulfilling nature, drive the business cycle and in turn are influenced by the business cycle.

The use of this behavioral model has allowed us to shed new light on the optimal level of the inflation target in a world where a lower zero bound constraint on the nominal interest rate exists. We found that when the inflation target is too close to zero, the economy can get gripped by "chronic pessimism" that leads to a dominance of negative output gaps and recessions, and in turn feeds back on expectations producing long waves of pessimism. The mechanism that produces this chronic pessimism can be described as follows. Endogenous movements in animal spirits regularly produce recessions and negative inflation rates. When that happens, the central bank cannot use its interest rate to boost the economy and to raise inflation as the nominal interest rate cannot become negative. When inflation becomes negative this also implies that the real interest rate increases during the recession, aggravating the latter, and increasing pessimism. The economy can get stuck for a long time in this cycle of pessimism and negative output gap.

We find, not surprisingly, that when the inflation target is close to zero the output gap and the rate of inflation will be pushed more often into negative territory than when the target is set farther away from zero, thereby producing more periods of “chronic pessimism”. Put differently, when the inflation target is set too close to zero the distribution of the output gap is skewed towards the negative territory.

The question then is what “too close to zero” means. The simulations of our model, using parameter calibrations that are generally found in the literature, suggests that 2% is too low, i.e. produces negative skewness in the distribution of the output gap. We find that an inflation target in the range of 3% to 4% comes closer to producing a symmetric distribution of the output gap. This also leads to the conclusion that central banks should raise the inflation target from 2% to a range between 3% to 4% (see also Blanchard, et al. (2010) and Ball(2014) on this).

One might object here that this conclusion does not take into account the potential negative effect on inflation credibility of raising the inflation target to 3% or 4%. We analyzed this question in the framework of our behavioral model. Our model gives a precise definition of credibility, as the fraction of agents that use the announced inflation target as their rule of thumb to forecast inflation. It turns out that an inflation target of 3% or 4% has more credibility than a target of 2%. The reason has to do with what we said earlier. With an inflation target of 2% the output gap and inflation are more often pushed into negative territory than when the inflation target is 3% or 4%. Once these variables are in the negative territory the power of the central bank to affect the output gap and inflation is weakened. As a result, the observed inflation rate will deviate more often from the target, thereby undermining the credibility of the central bank.

One issue that we have not analysed in this paper is how periods of prolonged pessimism that are produced by an inflation target that is set too low affects long term growth. It is not unreasonable to believe that “chronic pessimism” lowers investment in a persistent way thereby lowering long-term growth. As we have not incorporated these long-term growth effects in our model, it is difficult to come to precise conclusions. We leave this issue for further research.

In order to be fully convincing our model should be subjected to more intense empirical testing. We have not done so here in a systematic way. However, there is one prediction that we have checked. Our model predicts that the distribution of the output gap is non-normal, i.e. it exhibits excess kurtosis and fat tails. The latter are generated when the economy is gripped by extreme optimism or pessimism, leading to large positive or negative movements in output. This feature is also what drives most of our results. The existence of non-normality in the distribution of the output gap (and output growth) has been confirmed empirically for most OECD countries (see Fagiolo, et al., (2008), Fagiolo, et al., (2009), De Grauwe and Ji(2016)).

Appendix： parameter values of the calibrated model

```
a1 = 0.5;          %coefficient of expected output in output equation
a2 = -0.2;         %a is the interest elasticity of output demand
b1 = 0.5;          %b1 is coefficient of expected inflation in inflation equation
b2 = 0.05;         %b2 is coefficient of output in inflation equation
c1 = 1.5;          %c1 is coefficient of inflation in Taylor equation
c2 = 0.5;          %c2 is coefficient of output in Taylor equation
c3 = 0.8;          %interest smoothing parameter in Taylor equation
gamma = 2;         %intensity of choice parameter
sigma1 = 0.5;      %standard deviation shocks output
sigma2 = 0.5;      %standard deviation shocks inflation
sigma3 = 0.5;      %standard deviation shocks Taylor
rho=0.5;           %rho measures the speed of declining weights in mean
                   squares errors (memory parameter)
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