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INFLATION TARGETS AND THE ZERO LOWER BOUND IN A BEHAVIORAL MACROECONOMIC MODEL

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Abstract

In this paper 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. Low inflation targets create the risk of persistence of recessions and low growth.

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. We find that it leads to a relatively high probability of 25% of hitting the ZLB, thereby creating a negative skewness in the distribution of the output gap and persistence of recessions. 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 and persistent recessions.

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 ZLB and become more persistent than what commonly predicted by standard DSGE-models.

The paper is organized as follows. Section 2 presents the model and its main characteristics. Sections 3 to 6 present the results of this model: Section 3 focuses on the frequency distributions of output gap and animal spirits under different inflation target regimes; section 4 discusses the impulse responses of the different endogenous variables to demand and supply shocks; section 5 analyzes how inflation targets affect the persistence of recessions and section 6 discusses credibility issues resulting from increasing the inflation target. Section 7 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:

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

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 New Keynesian Philips curve with a forward looking component, $\widetilde{\mathrm{E}}_t \pi_{t+1}$, and a lagged inflation variable[1] :

[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

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

Finally the Taylor rule describes the behavior of the central bank

$$r_t = k_3[\pi^* + k_1(\pi_t - \pi^*) + k_2 y_t] + (1-k_3) r_{t-1} + u_t \quad (3)$$

where π^* is the inflation target; The central bank is assumed to smooth the interest rate. This smoothing behavior is represented by adding a fraction of the lagged interest rate r_{t-1} in equation (3). For simplicity we assume that the long-term equilibrium interest rate is zero and thus it does not appear in equation (3).

2.1 Normalizing the model

In order to solve the behavioral model following De Grauwe(2012), we first normalize the inflation rate and the interest rate. i.e. we express them as deviations from the inflation target π^*. We define these deviations as: $\pi'_t = \pi_t - \pi^*$, $r'_t = r_t - \pi^*$ and $r'_{t-1} = r_{t-1} - \pi^*$, and $E_t \pi'_{t+1} = E_t \pi_{t+1} - \pi^*$.

Equations (1)-(3) can now be rewritten in normalized form as follows:

$$y_t = a_1 \widetilde{E}_t y_{t+1} + (1-a_1) y_{t-1} + a_2\left(r'_t - \widetilde{E}_t \pi'_{t+1}\right) + \varepsilon_t \quad (1a)$$

$$\pi'_t = b_1 \widetilde{E}_t \pi'_{t+1} + (1-b_1)\pi'_{t-1} + b_2 y_t + \eta_t \quad (2a)$$

$$r'_t = c_1 \pi'_t + c_2 y_t + c_3 r'_{t-1} + u_t \quad (3a)$$

where $c_1 = k_1 k_3, c_2 = k_2 k_3, c_3 = 1 - k_3$.

2.2 Introducing heuristics in forecasting output

Agents are assumed to use simple rules (heuristics) to forecast the future output $\widetilde{E}_t y_{t+1}$. 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

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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)).

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 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.

$$\widetilde{E}_t y_{t+1} = \alpha_{f,t} \widetilde{E}_t^f y_{t+1} + \alpha_{e,t} \widetilde{E}_t^e y_{t+1} \quad (6)$$

$$\widetilde{E}_t y_{t+1} = \alpha_{f,t} 0 + \alpha_{e,t} y_{t-1} \quad (7)$$

and $$\alpha_{f,t} + \alpha_{e,t} = 1 \quad (8)$$

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

[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.

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].

2.3 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 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:

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

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

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

[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).

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

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

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.

2.4 Heuristics and selection mechanism in forecasting inflation

Agents also have to forecast inflation $\widetilde{\mathrm{E}}_t \pi_{t+1}$. 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.

$$\widetilde{E}_t^{tar}\pi_{t+1} = \pi^* \quad (14)$$

or after normalization $\widetilde{E}_t^{tar}\pi'_{t+1} = 0$

where the inflation target is π^*

The "extrapolators" are defined by

$$\widetilde{E}_t^{ext}\pi_{t+1} = \pi_{t-1} \quad (15)$$

or after normalization $\widetilde{E}_t^{ext}\pi'_{t+1} = \pi_{t-1} - \pi^*$

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

$$\widetilde{E}_t\pi'_{t+1} = \beta_{tar,t}\widetilde{E}_t^{tar}\pi'_{t+1} + \beta_{ext,t}\widetilde{E}_t^{ext}\pi'_{t+1} \quad (16)$$

or

$$\widetilde{E}_t\pi'_{t+1} = \beta_{tar,t}0 + \beta_{ext,t}(\pi_{t-1} - \pi^*) = \beta_{ext,t}\pi'_{t-1} \quad (17)$$

and

$$\beta_{tar,t} + \beta_{ext,t} = 1 \quad (18)$$

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 in equation (21) and (22). 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.

$$U_{tar,t} = -\sum_{k=0}^{\infty}\omega_k\left[\pi_{t-k-1} - \widetilde{E}_{f,t-k-2}\pi_{t-k-1}\right]^2 \quad (21)$$

$$U_{ext,t} = -\sum_{k=0}^{\infty}\omega_k\left[\pi_{t-k-1} - \widetilde{E}_{e,t-k-2}\pi_{t-k-1}\right]^2 \quad (22)$$

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.

2.5 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:

$$S_t = \begin{cases} \alpha_{e,t} - \alpha_{f,t} & if\ y_{t-1} > 0 \\ -\alpha_{e,t} + \alpha_{f,t} & if\ y_{t-1} < 0 \end{cases} \tag{23}$$

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 (23) as follows:

$$S_t = \begin{cases} \alpha_{e,t} - (1 - \alpha_{e,t}) = 2\,\alpha_{e,t} - 1 & if\ y_{t-1} > 0 \\ -\alpha_{e,t} + (1 - \alpha_{e,t}) = -2\,\alpha_{e,t} + 1 & if\ y_{t-1} < 0 \end{cases} \tag{24}$$

2.6 Solving the model

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

$$\begin{bmatrix} 1 & -b_2 \\ -a_2c_1 & 1 - a_2c_2 \end{bmatrix} \begin{bmatrix} \pi'_t \\ y_t \end{bmatrix}$$

$$= \begin{bmatrix} b_1 & 0 \\ -a_2 & a_1 \end{bmatrix} \begin{bmatrix} \widetilde{\mathrm{E}}_t \pi'_{t+1} \\ \widetilde{\mathrm{E}}_t y_{t+1} \end{bmatrix} + \begin{bmatrix} 1 - b_1 & 0 \\ 0 & 1 - a_1 \end{bmatrix} \begin{bmatrix} \pi'_{t-1} \\ y_{t-1} \end{bmatrix} + \begin{bmatrix} 0 \\ a_2c_3 \end{bmatrix} r'_{t-1} + \begin{bmatrix} \eta_t \\ a_2u_t + \varepsilon_t \end{bmatrix}$$

Or

$$\boldsymbol{AZ_t} = \boldsymbol{B\widetilde{E_t}\,Z_{t+1}} + \boldsymbol{CZ_{t-1}} + \boldsymbol{b}r'_{t-1} + \boldsymbol{v_t} \tag{25}$$

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

$$\boldsymbol{Z_t} = \boldsymbol{A^{-1}}\left[\boldsymbol{B\widetilde{E_t}\,Z_{t+1}} + \boldsymbol{CZ_{t-1}} + \boldsymbol{b}r'_{t-1} + \boldsymbol{v_t}\right] \tag{26}$$

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 (26) 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 (7) and (17) and therefore can be

substituted into (26). Finally, the solution for r'_{t-1} is found by substituting y_t and π_t obtained from (26) into (3a).

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:

$$\mathrm{r_t} \geq 0 \tag{25}$$

$$\text{Or} \quad r'_t \geq -\pi^* \tag{26}$$

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.

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).

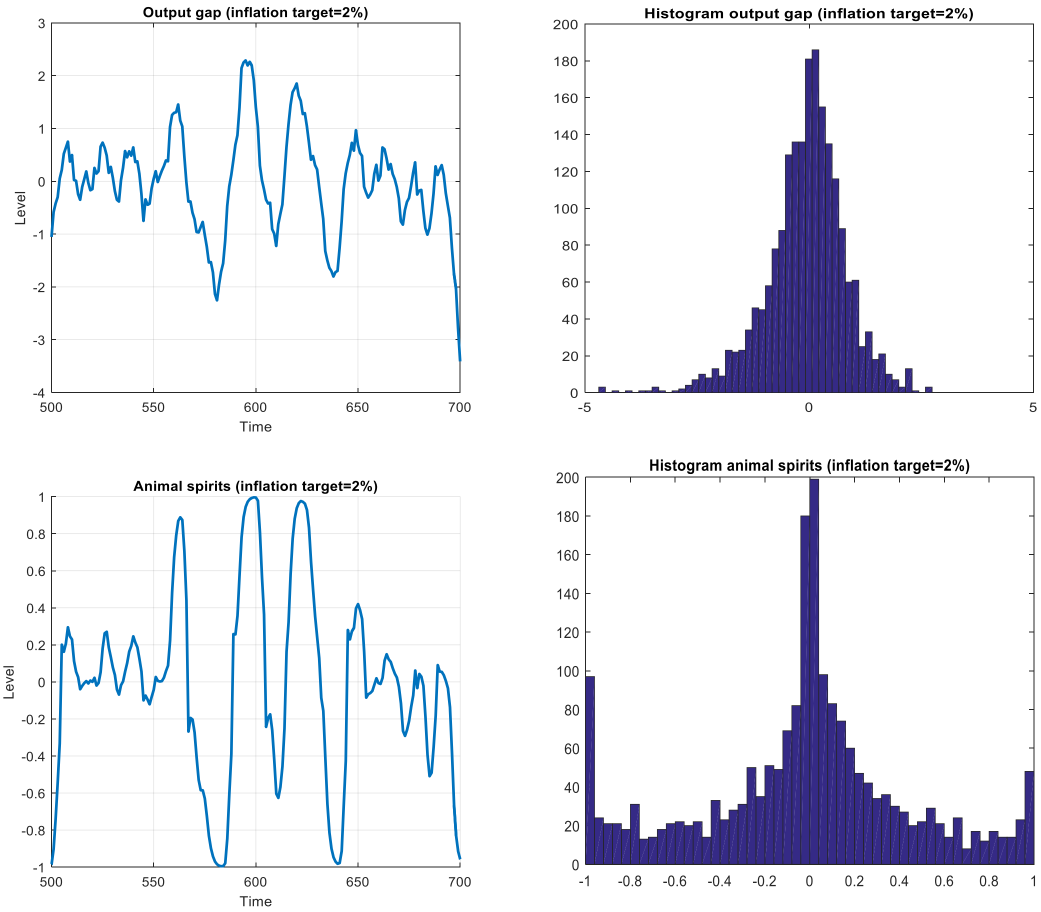
As can be seen from the left hand side panels, the correlation of these animal spirits and the output gap is high. In the simulations reported in figure 1 this correlation reaches 0.94. Underlying this correlation is the self-fulfilling nature of expectations. When a wave of optimism is set in motion, 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.

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.

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



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%)

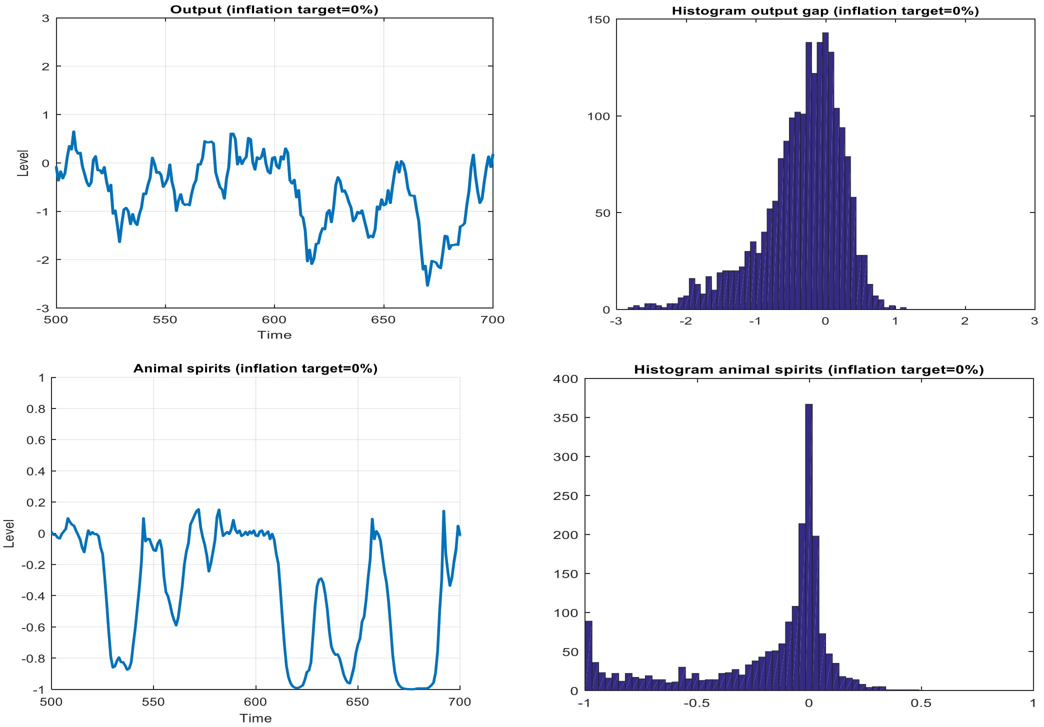
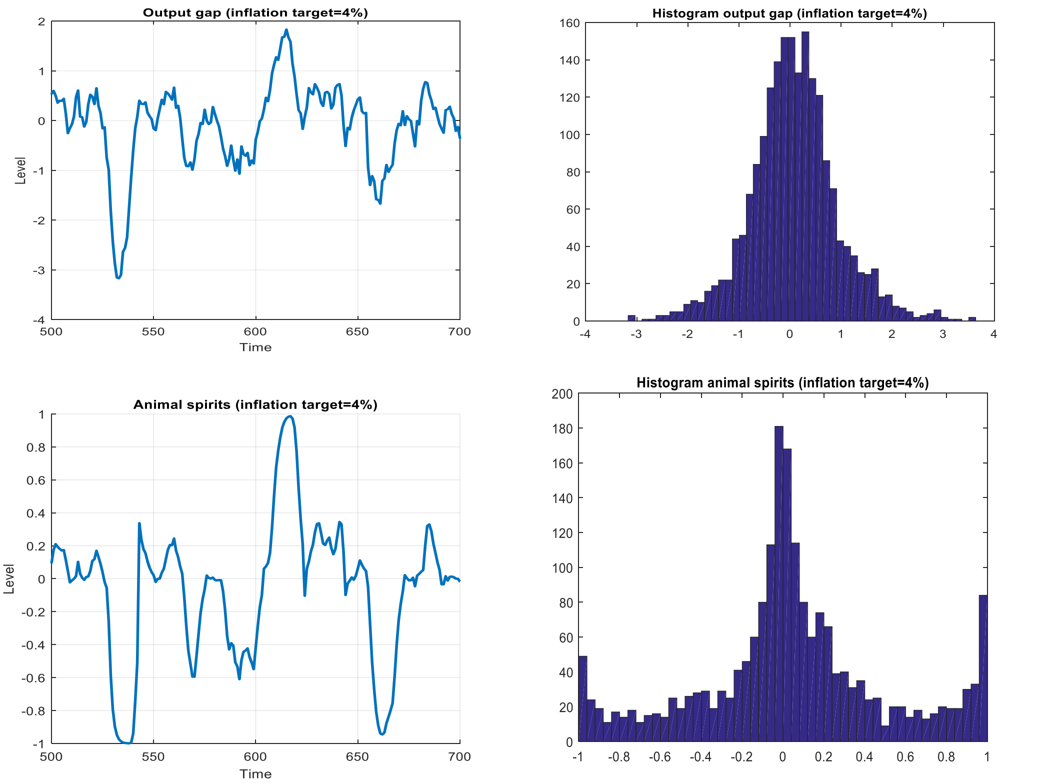


Figure 3: Output gap and animal spirits in time and frequency domains (Inflation target = 4%)



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:

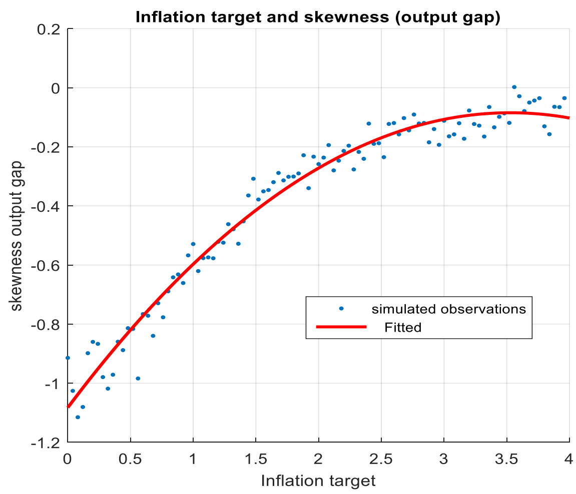
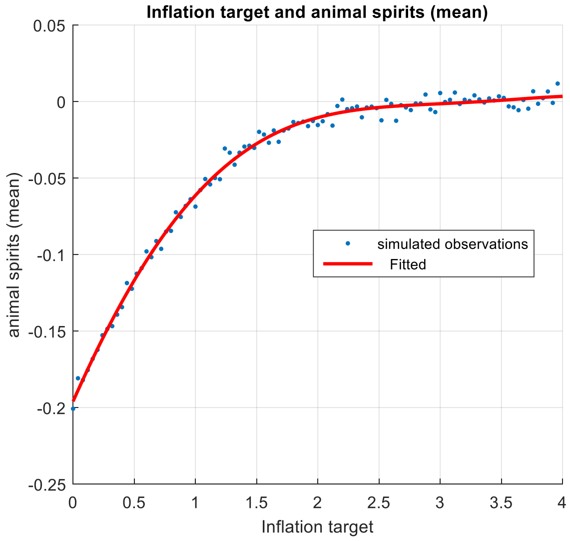


Figure 5

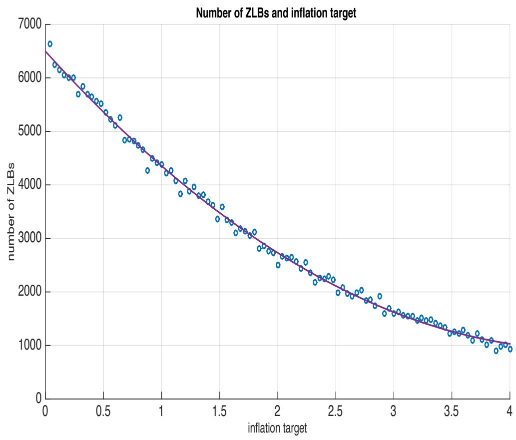


How can these results be interpreted? When the inflation target is 0% the cyclical movements in output gap and animal spirits inevitably lead to recessions that also drive inflation into negative territory. When that happens the zero bound constraint that applies to the nominal interest rates makes it 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, 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%-4% is probably better than 2% in making sure that the economy does not get stuck in the chronic pessimism trap.

Finally Figure 6 shows the relationship between the inflation target and the number of times the interest rate hits the ZLB. We obtained this figure by simulating the model 10000 times for each level of the inflation target. The vertical axis shows the number or times the interest rate hits the ZLB (out of 10000). We observe that as the inflation target is increased the probability of hitting the ZLB declines considerably. At 2% of inflation target level, the

probability is about 25% which is significantly higher than what most standard DSGE models predict.

Figure 6



4. Impulse responses to demand and supply shocks

In this section we compute impulse responses to demand and supply shocks assuming different levels of inflation target. We will assume three different inflation targets 0%, 2% and 4%. These impulse responses are expressed as "multipliers", i.e. the output responses to the shock are divided by the shock itself (which is two standard deviations of the error terms in the demand and supply equations).

In contrast to linear rational expectations models the impulse responses depend on the timing of the shock. Put differently, an impulse response computed with one realization of the stochastic shocks in the demand and supply equations of the model will be different from an impulse response to exactly the same shock but performed using another realization of these stochastic shocks. This is the case even when all parameters of the model are identical. We illustrate this by presenting two impulse responses of the output gap to a demand shock (Figures 6 and 7). Thus it appears that there is great uncertainty about the transmission of a shock even if the parameters of the model are known with certainty, as this transmission depends on "initial conditions", i.e. on the configuration of stochastic disturbances that prevail at the moment the demand shock occurs. In our model the timing of the shock matters.

Figure 6: Impulse responses of output to negative demand shocks

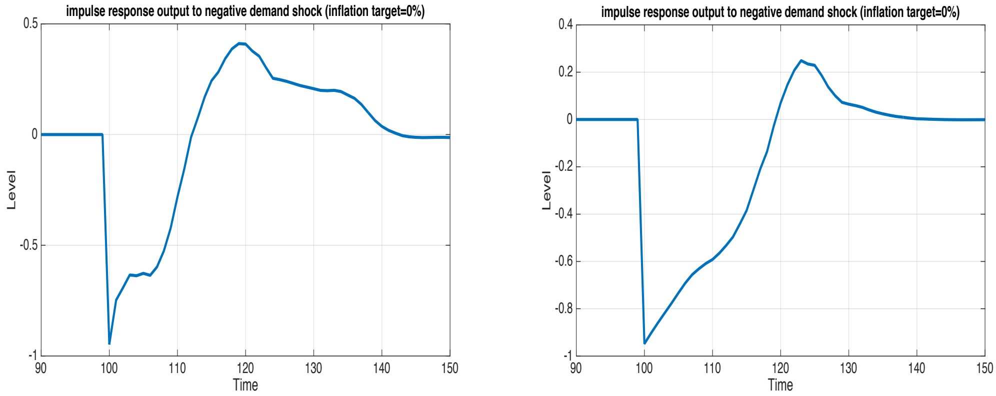
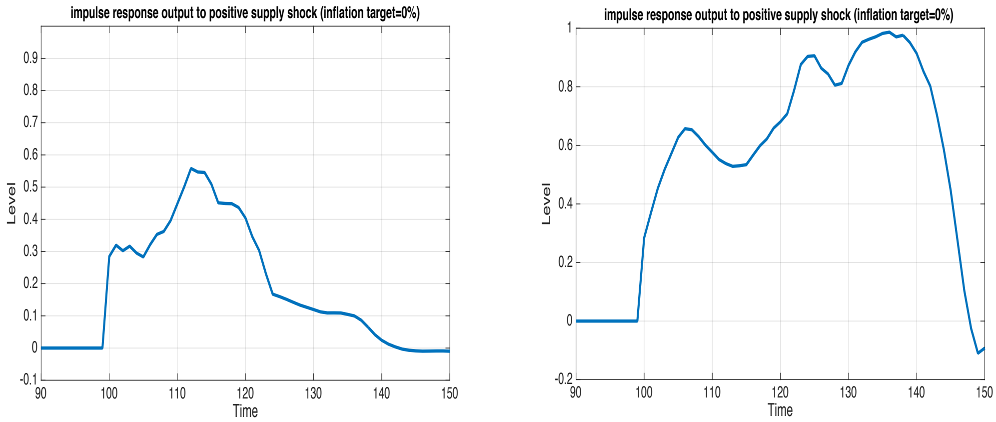


Figure 7: Impulse responses of output to positive supply shocks



This result can be made even more precise by presenting the frequency distributions of the short-term effects of demand and supply shocks. We concentrate here on how the latter shocks affect the output gap and animal spirits in the short run. These frequency distributions were derived as follows. We simulated 1000 impulse responses to the same shock (demand respectively supply), assuming each time a different realization of stochastic shocks. We then collected the impulse response obtained in the 5^{th} period after the shock occurred. In so doing we obtained 1000 short-term output responses and 1000 short-term responses of animal spirits. We plot these in the frequency domain. We did the same for the short-term output responses following a supply shock. We performed the impulse responses for three different levels of the inflation target (0%, 2%, 4%). The results are shown in Figures 8 and 9.

The first striking aspect of the results is the extreme variation of the short-term responses to these shocks. To repeat, this variation is only related to the fact that the 1000 simulations of the demand, respectively the supply shocks occur with different "initial conditions" (different realizations of stochastic shocks). As mentioned earlier, it matters a great deal when these shocks occur. For example, the effect of the *demand* shock may be very different depending on whether the shock occurs during a recession, a boom or in more normal business cycle conditions.

4.1 Short-term impulse responses to demand shocks

We concentrate our attention first on the demand shocks (Figure 8). These are *negative* shocks[4]. The most striking result in Figure 8 is the fact that when the inflation target *increases* the negative impact on output following a negative demand shock *declines* significantly, *on average*. At the same time, the short-term responses in animal spirits are on average more negative with a low inflation target than with a high one. But as mentioned earlier, there is a wide variation in the short-term effect of the same demand shock on output and animal spirits.

In Figure 9 we present the short-term interest rate responses that are associated with the responses in output and animal spirits shown in Figure 8. We find that when the inflation target is zero, the interest rate response to the negative demand shock is zero in more than half of the cases (1000 replications of the same shock). In other words when the inflation target is zero the negative demand shock leads the interest rate to hit the ZLB in more than half of the cases. When the inflation target increases to 2% we see that the number of times the interest rate is constrained by the ZLB is reduced significantly. It almost completely disappears when the inflation target is 4%.

The mechanism that drives these results is the same as the one we unveiled in the previous sections. With a zero inflation target there is little scope for output stabilization following a negative demand shock because the interest rate is very

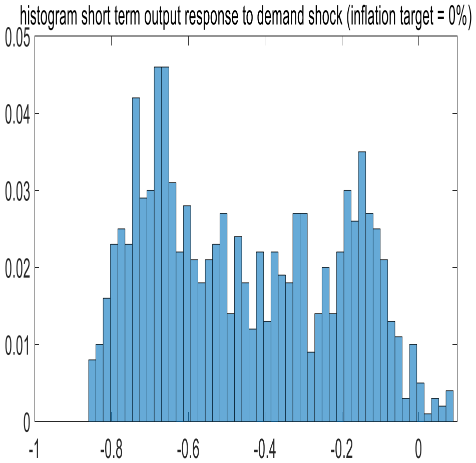
[4] We do show impulse responses to positive demand shocks. The reason is that when positive shocks occur the central bank, that wishes to raise the interest rate, is not constrained by the ZLB. As a result, impulse responses are pretty much the same for different levels of the inflation targets.

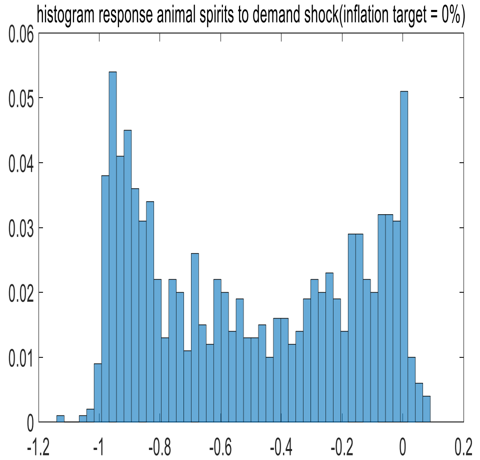
likely to hit the ZLB. As a result, this shock will have a stronger negative output effect in a low inflation target environment as compared with a high inflation target environment. Animal spirits amplify these differences. When the inflation target = 0% the negative demand shock together with the inability of the central banks to stimulate output by reducing the interest rate creates more pessimism than when the inflation target = 4% (see figure 8). In the latter case the central bank is capable of stabilizing output. This in turn reduces pessimism and reinforces the stabilization effort of the central bank.

Figure 8: Frequency distribution of short-term responses to negative demand shock

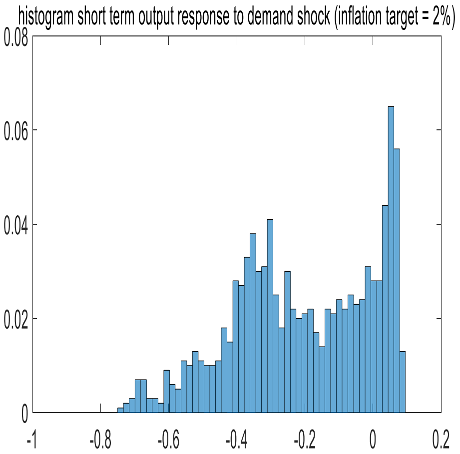
Output responses | **Responses animal spirits**

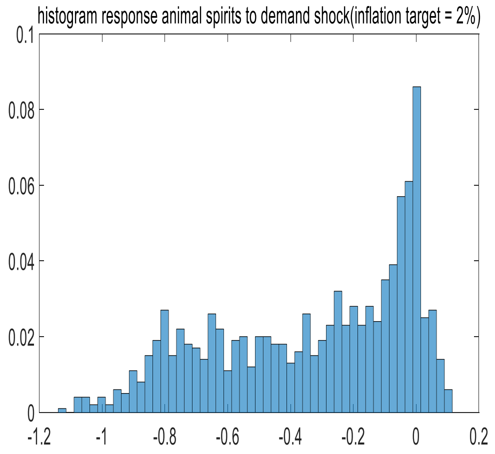
Inflation target=0%



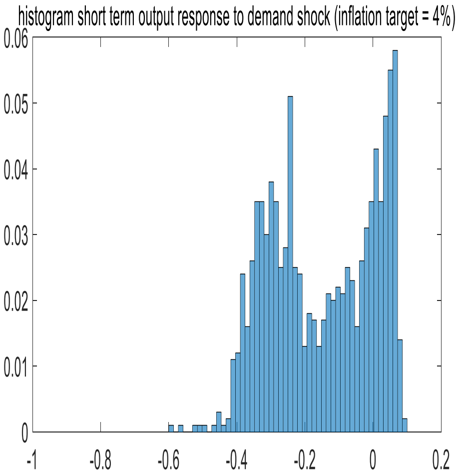


Inflation target=2%





Inflation target=4%



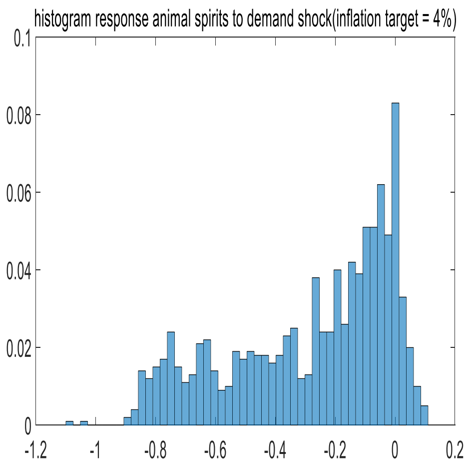
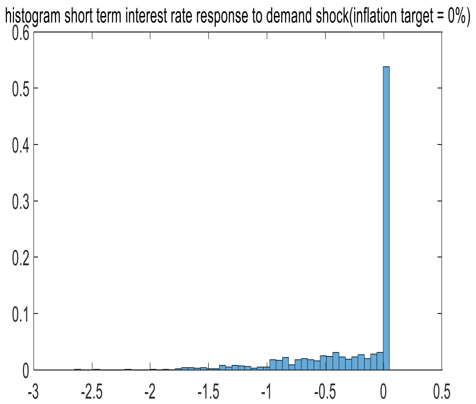
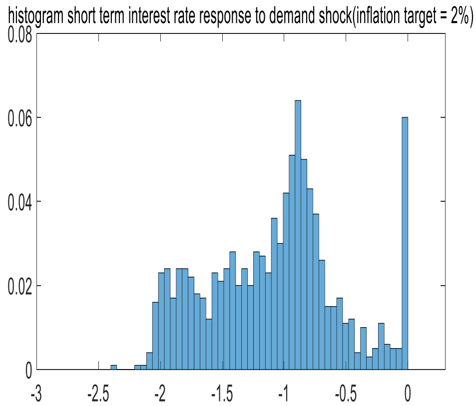


Figure 9: Frequency distribution of short-term interest rate response to negative demand shock.

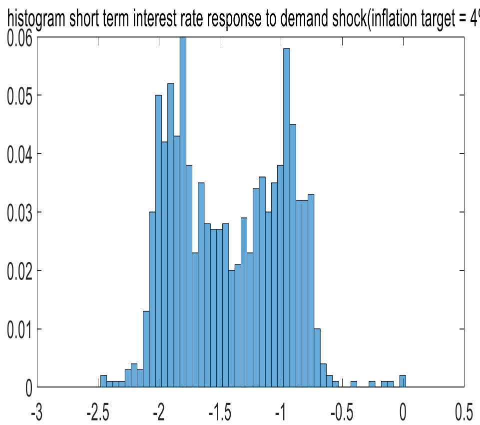
Inflation target = 0%



Inflation target = 2%



Inflation target = 4%



4.2 Short-term impulse responses to supply shocks

In this section we analyze the short-term impulse responses of output, animal spirits and the interest rate following a positive supply shock. The positive supply shock can be interpreted as a positive shock in productivity, shifting the supply curve downwards and producing a decline in the rate of inflation. An inflation targeting central bank will react to this decline in the rate of inflation by lowering the interest rate. The capacity to do so, however, is limited if the inflation target is low (0%). It increases when the inflation target is raised. The

effects are shown in Figures 10 and 11. Figure 10 shows the output responses and the responses of animal spirits to the positive supply shock.

We observe from Figure 10 that in a regime of high inflation targeting (4%) the impact of the positive supply shock on output gap is amplified as compared to the case of low inflation target (0%). The inflation targeting regime of 2% is intermediate, although we observe that the amplification effect is quite strong. Thus the 2% and 4% inflation targeting regimes are not very different as far as their effects of positive supply shocks are concerned.

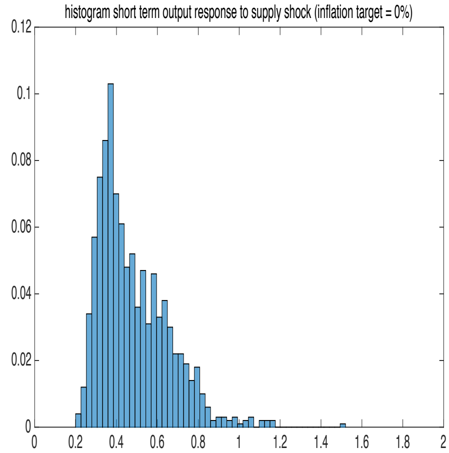
This is also made clear when we compare the responses of animal spirits and interest rates in the different regimes. The high (4%) and “mild” (2%) inflation targeting regimes are characterized by strong positive effects on animal spirits. Thus in those regimes the positive supply shock lead to a strong increase in optimism. This is much less the case in the low inflation targeting regime (0%).

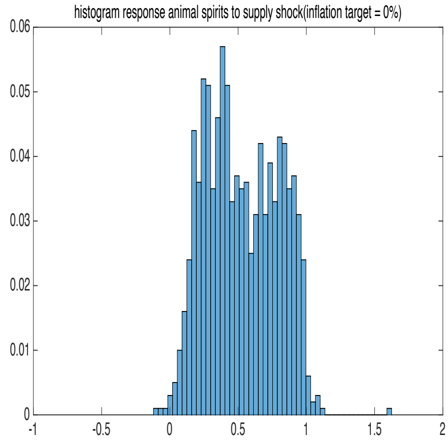
The underlying mechanism that drives these differences are the different interest rate responses to the positive supply shock. In the high and mild inflation targeting regimes the central bank reacts by lowering the interest rate thereby fueling the supply shock. In the low inflation targeting regime the central bank is constrained by the ZLB and is prevented from fueling the supply shock by an expansionary monetary policy.

Figure 10: Frequency distribution of short-term output responses to positive supply shock

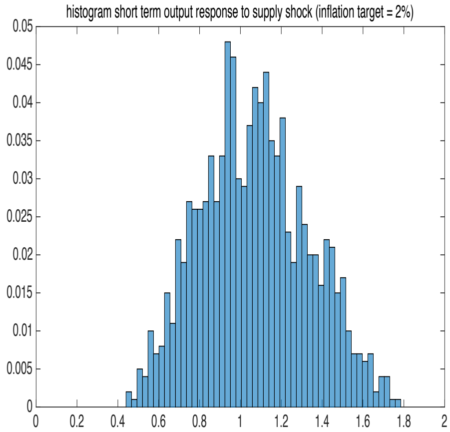
Output responses | **Responses animal spirits**

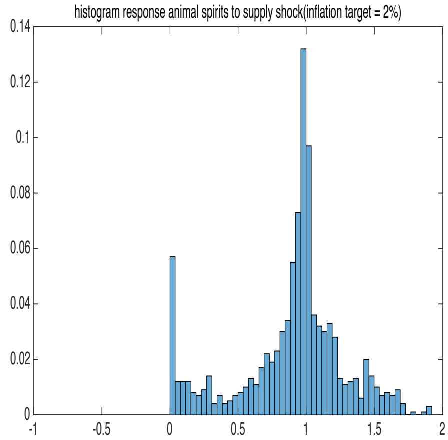
Inflation target=0%



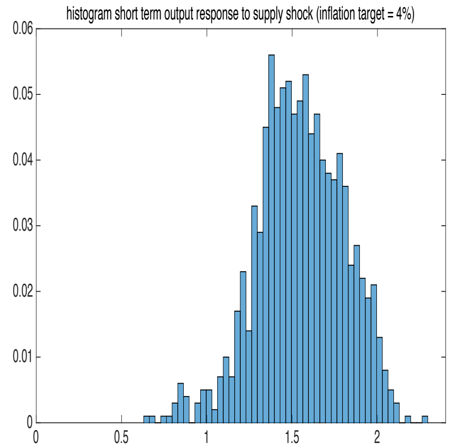


Inflation target=2%





Inflation target=4%



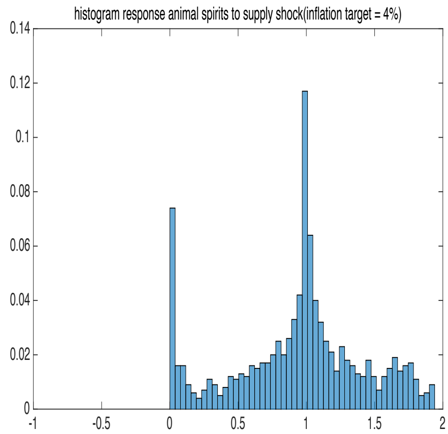
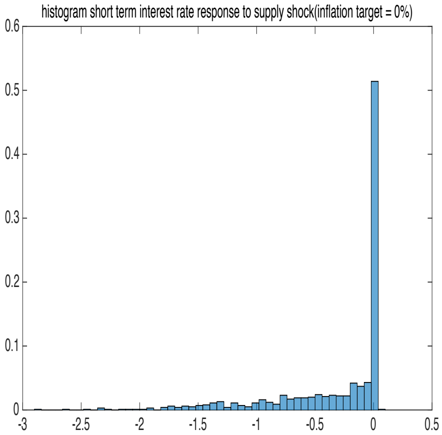
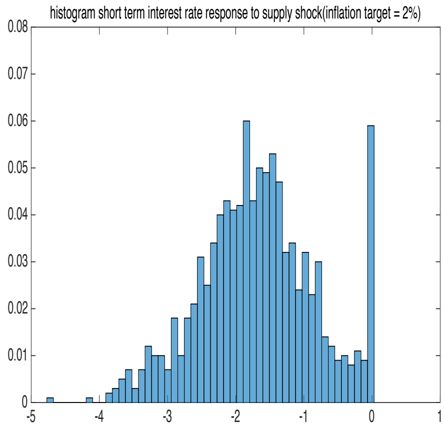


Figure 11: Frequency distribution of short-term interest rate response to positive supply shock.

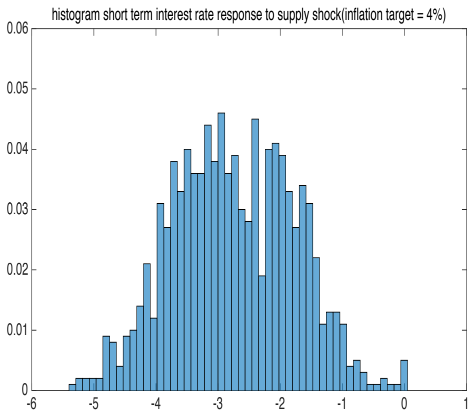
Inflation target = 0%



Inflation target = 2%



Inflation target = 4%



5. Analysis of the deterministic model

In this section we analyze the deterministic version of the model, i.e. we strip the model of all the stochastic shocks. This will allow us to shed some light on the steady state characteristics of the model and the speed with which the variables return to their steady state values after an initial disturbance.

We proceed as follows. We apply an initial disturbance in demand and in supply. We will restrict ourselves to an initial negative shock in demand and an initial positive shock in supply (a negative inflation shock).

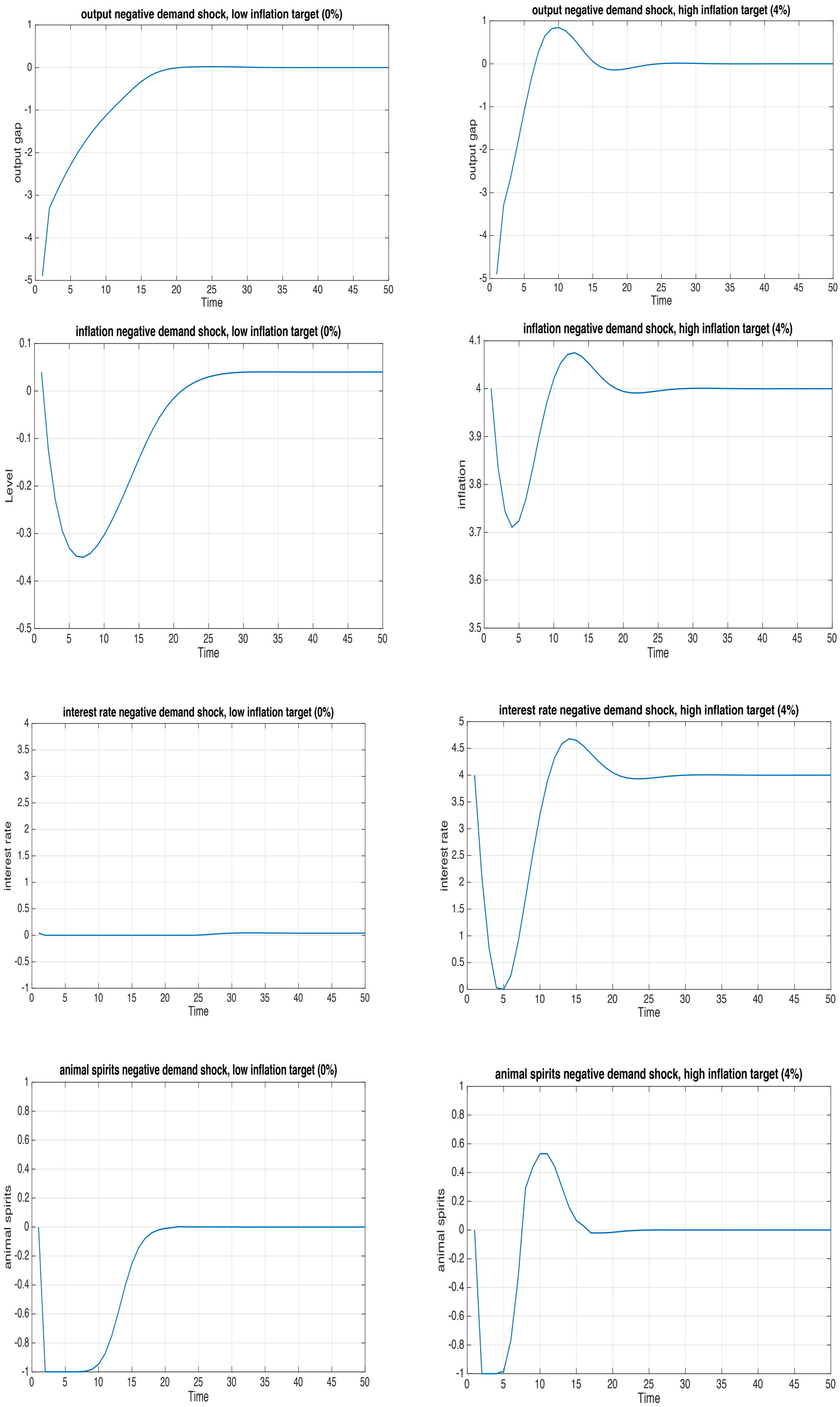
5.1 A negative demand shock

In Figure 12 we show how the output gap, animal spirits, inflation and the interest rates react to an initial negative shock in aggregate demand. We perform this exercise in the context of a low inflation target regime (target = 0%) and a high inflation target regime (target = 4%). We selected a rather large shock of -5. As mentioned earlier, these are deterministic simulations, i.e. by switching off all stochastics we trace the response of the endogenous variables that is not influenced by noise. As we showed in the previous section stochastic noise has a great influence on the transmission process.

A first noteworthy result is that the negative demand shock has a significantly more protracted negative effect on the output gap in the low inflation target regime as compared to the high inflation target regime. When the inflation target is 0% it takes 20 periods for the economy to get out of the recession (i.e. for the negative output gap to become 0). In contrast when the inflation target is 4% the economy climbs out of the recession after 7 periods. This has to do with the fact that in the low inflation target regime the central bank cannot lower the interest rate while in the high inflation target regime the central bank is not constrained in stimulating the economy by lowering the interest rate. Not only the interest rate matters. We observe that in the low inflation target regime animal spirits are kept in negative territory longer than in the high inflation target regime. Thus, it appears that when the central bank sets a relatively high inflation target, the capacity of the system to lift itself out of the recession is stronger than when it sets a low inflation target. This is made possible by the stabilizing properties of monetary policies and by the ensuing elimination of self-fulfilling pessimism.

One can conclude that a high inflation target regime allows for better stabilization when negative demand shocks occur than a low inflation target regime.

Figure 12: Initial negative demand shock

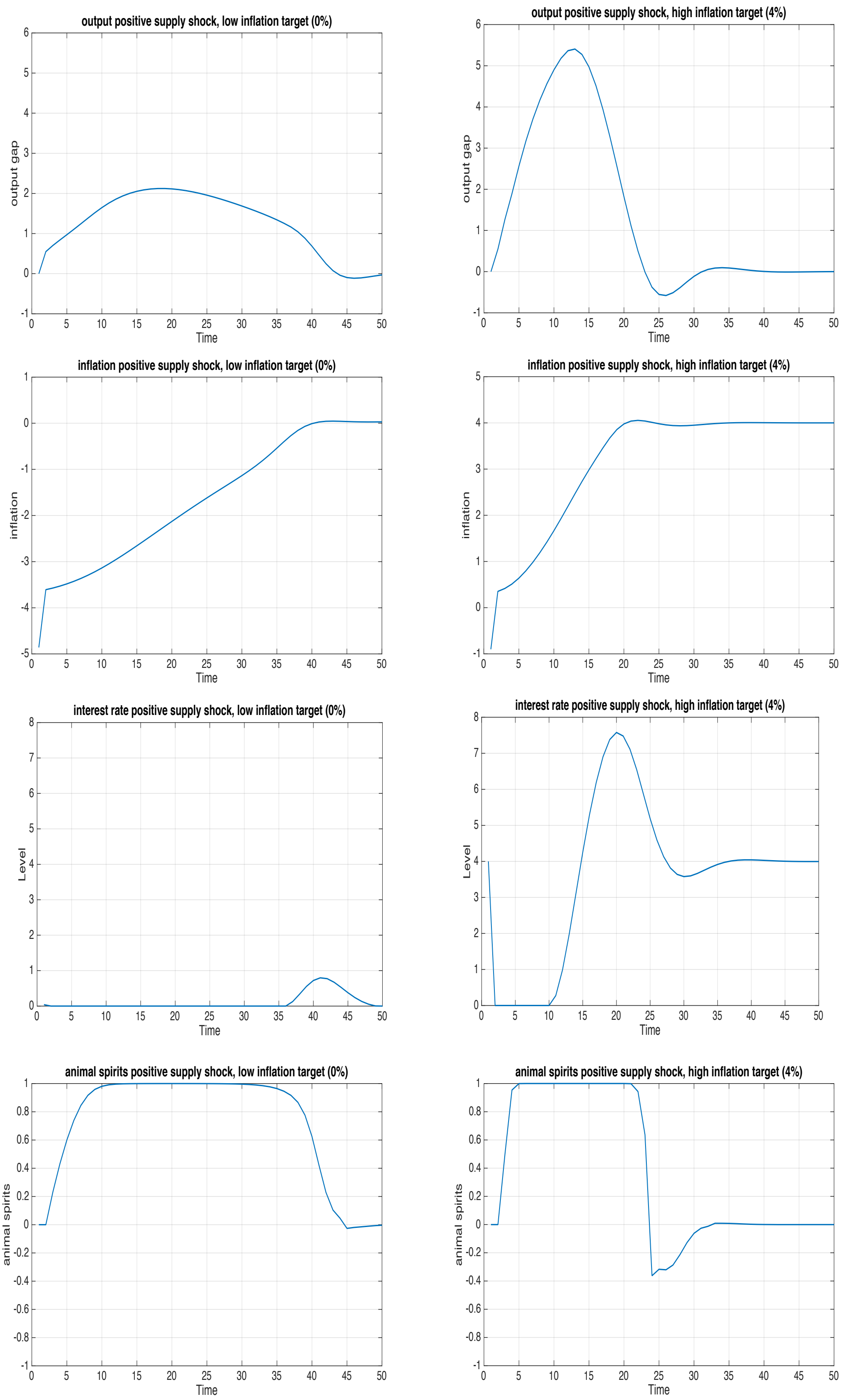


5.2 A positive supply shock

Figure 13 shows the effects of an initial positive supply shock. This shock has the effect of reducing the rate of inflation and to stimulate output. In the high inflation target regime this leads the central bank that attaches a relatively high weight to inflation to lower the interest rate so as to maintain its inflation target. This policy reaction has the effect of amplifying the output boom produced by the supply shock. In the low inflation regime this amplification effect is absent. In fact, since the rate of inflation becomes negative and since the central bank cannot lower the nominal interest rate, the real interest rate increases, thereby strongly reducing the impact of the supply shock on output. Thus, in the high inflation target regime, monetary policy tends to amplify the output effect of a positive supply shock; in a low inflation target regime the opposite occurs: the central bank tends to dampen the output effect of a positive supply shock.

The two inflation target regimes also differ in the speed with which the system returns to the steady state. In the high inflation target regime the return to the steady state is significantly faster than in the low inflation target regime. This has to do with the fact that the central bank reverses its interest rate policy much quicker in the former than in the latter case. This then also has the effect of leading animal spirits out of their "euphoric" state (animal spirits=+1) faster in the high inflation as compared to the low inflation target regime. In this sense, i.e. the capacity of the central bank to steer the economy towards its steady state, the high inflation target regime performs better than the low inflation target regime when a positive supply shock occurs. This is a similar conclusion as the one derived in the previous section.

Figure 13: Initial positive supply shock



6. Credibility of inflation targeting and the zero lower bound

An objection to the idea that central banks should adopt a higher inflation target is that this would negatively affect their credibility. We analyze this question of credibility in this section.

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.

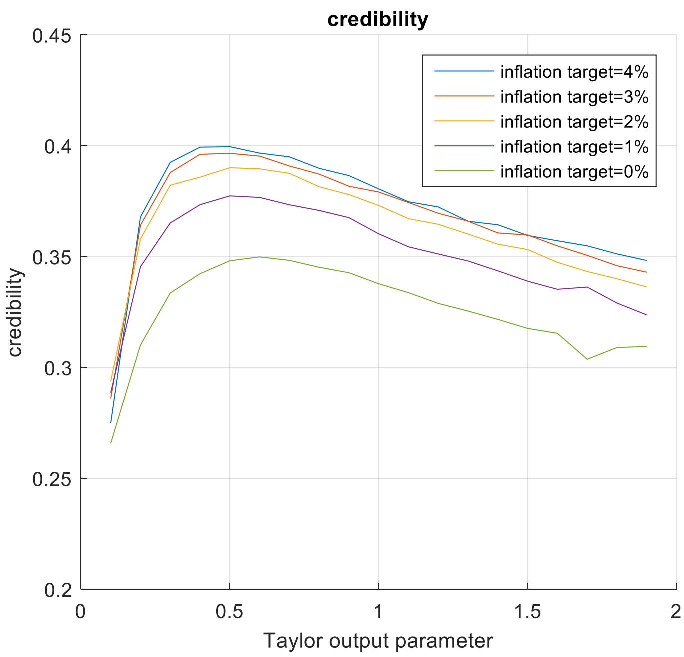
We used this insight to compute an index of inflation credibility, which we define to be the fraction of "targeters", $\beta_{tar,t}$ as shown in equations (16)-(18). We then computed this index for different values of the Taylor output parameter and the inflation target. We show the result in Figure 15.

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. This result can be given the following interpretation. When the central bank starts increasing its stabilization efforts, 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. When the central bank uses too much output stabilization, however, it undermines its inflation credibility and as a result the credibility decreases. Note that the empirical literature reveals that central banks tend to set the Taylor output parameter close to 0.5. We discuss this result more in details in De Grauwe (2012).

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 regardless of whether the central bank applies little or much output stabilization. This result can be given the following interpretation. 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.

Figure 15: Credibility and inflation targets



7. Conclusion

In this paper we have analyzed the relation between the level of the inflation target and the ZLB 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 ZLB 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 very long time in this cycle of pessimism and negative output gap.

Thus, 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.

We also found that when the economy is pushed into a recession as a result of a negative demand shock, the high inflation target regime has better stabilizing properties. We found that in the high inflation target regime the persistence of

the recession is much shorter than in the low inflation target regime. That is, when the central bank sets a relatively high inflation target, the capacity of the system to lift itself out of the recession is stronger than when it sets a low inflation target. This is made possible by the stabilizing properties of monetary policies and by the ensuing elimination of self-fulfilling pessimism.

Another major finding of our analysis is that with an inflation target of 2% (which has become the standard in inflation targeting) the economy hits the ZLB with a probability of 25% compared to less than 10% with an inflation target of 4%. These are significantly higher probabilities than those obtained in standard DSGE models. The reason we find significantly higher probabilities has to do with the fact that animal spirits amplify shocks and in combination with the ZLB can keep the economy in a persistent way into negative territory.

The previous results 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 inflation and output gap 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, when the target is low, 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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