Inflation targeting in a learning economy: an ABM perspective

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Abstract

Most of theoretical approaches of the inflation targeting regime and performances have adopted the New Keynesian macroeconomic modeling framework (NK model). In this paper, we adopt an alternative approach, using an agent-based macroeconomic model, to reevaluate two core dimensions of inflation targeting – the credibility and the accuracy of the announced inflation target. While the structure of this model has common features with that of the NK model, it departs from the latter on three main grounds: first, individual agents are not assumed to fully optimize on an intertemporal basis beforehand and to make use of rational expectations in this respect; second, interaction and coordination mechanisms between agents must be explicitly introduced in the model so as to ensure the consistency of their mutual decisions. Finally, agents are engaged in a continuous learning process, according to which they take into account the disclosure of information by the Central Bank so to form their inflation expectations. This setting allows us to highlight the primary role of credibility of central bank's announcements for macroeconomic stabilization and to underline how unanchored inflation expectations restrict the ability of the Taylor rule to achieve both inflation and employment objectives of monetary policy. We also contribute to the debate on the potential welfare cost of imperfect public information.

Key-words – inflation targeting, agent-based model, central bank communication, expectations, learning.

1 Introduction

The last two decades have seen the emergence of a new paradigm in the way monetary policy should be conducted. At the heart of it stands the idea that expectations are the primary concern of central banks (CB). Policy decisions should be transparent to make them predictable for the economic agents, so that the CB is able to *manage* their expectations (Woodford (2003)). Along these lines, inflation targeting has become a popular way of conducting monetary policy[1]. Indeed, inflation targeting implies at least two points which are clearly consistent with the claim for transparency: "i) an explicit long-run inflation goal and ii) a strong commitment to transparency regarding all goals and aspects of policy" (Faust & Henderson (2004)). The role of the inflation target appears twofold.

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[1] *see* Schmidt-Hebbel (2009) and Walsh (2009) for recent surveys of inflation targeting experiences, *see* Bernanke et al. (1999) for an earlier one.

On the one hand, an explicit inflation target acts as a reference point for the evaluation of monetary policy, and the CB can build its credibility regarding its primary objective of maintaining price stability. This credibility gain then allows the CB to better stabilize the economy when facing shocks, in keeping inflation expectations well-anchored to its target. Herewith, this enhances macroeconomic performance of monetary policy. On the other hand, the target acts as an anchor for the coordination of private inflation expectations. This meets the need for a nominal anchor after the abandonment of currency pegs. Inflation targeting is therefore based on two dimensions: the credibility and the clarity of the announced target.

Most of theoretical frameworks consider inflation targeting within the New Keynesian modeling[2]. This uses dynamic stochastic general equilibrium models, which rely on strong assumptions: the macroeconomic dynamics result from the aggregation of microeconomic optimizing behaviors. Agents are supposed to be identical, fully rational and endowed with the whole information concerning the model of the economy and the behaviors of the other agents. The rational expectations hypothesis allows their behaviors to be mutually consistent and rules out any coordination issues. In this context, the usefulness of CB' communication appears questionable (Preston (2006), Blinder et al. (2008)). King (2005) and Orphanides & Williams (2007) rather argue that inflation targeting is designed for a world where agents do not form rational expectations nor perfectly know the true model of the economy but are perpetually learning from their environment and use simple rules of thumb. The CB communication aims, then, at making easier the agents' learning and prevision process in simplifying the understanding of the complex economic system (Faust & Henderson (2004), Dennis & Ravenna (2008)).

A part of the academic research has introduced learning within these kinds of models[3]. However, these analyses focus on the properties of the monetary policy rules under least squares learning without any reference to the CB communication or the announcement of an inflation target. Few recent contributions try to explicitly link these aspects of monetary policy with the agents' learning process. These include Orphanides & Williams (2005, 2007) and Eusepi & Preston (2010). They remain close to the analytical framework of New Keynesian models except that agents do not hold rational expectations but inflation and output gap forecasts are derived from a VAR model with least square learning. This departure from the rational expectations assumption introduces further macroeconomic volatility in front of shocks. Orphanides and Williams show how the explicit announcement of the inflation target allows inflation expectations to remain close to the CB objectives when facing shocks and herewith, enhances the trade-off the CB faces between both objectives. Eusepi & Preston (2010) add to this framework the feedback of expectations into macroeconomic dynamics. In this context, they show that, not only the explicit target is needed to, at least, partially offset the effects of non-fully rational expectations on macroeconomic dynamics, but also the disclosure of the rule, including its variables and its coefficients.

However, least square learning still require strong rationality assumption. Agents are especially supposed to know the true form of the underlying model. In De Grauwe (2010), agents rather use simple heuristic rules to forecast inflation and output gap. Credibility endogeneously spreads among households through an evolutionnary social learning algorithm. This model underlines the macroeconomic instability arising from the departure from the rational expectations benchmark and from imperfect credibility of the inflation target. In both cases, the trade-off the CB faces between its both objectives is made steeper. Note that all these contributions assess inflation targeting in log-linearized versions of DSGE models. For this version to hold, only small distubances can be introduced

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[2] *see* Woodford (2003) for a complete treatment.

[3] *see* more particularly Evans & Honkapohja (2001) and Bullard & Mitra (2002).

and macroeconomic dynamics have to evolve close to the rational expectations equilibrium. To this respect, Canzian (2009, chap. 4) uses a simple aggregate model without any microfundations and confirms the above discussed findings.

In this paper, we reevaluate the two core dimensions of inflation targeting – credibility and accuracy of the announced inflation target – in an agent-based model, whose base structure is close to those of New Keynesian models[4]. This proximity allows to keep our analysis close to most of the recent works in macroeconomics without the strong assumptions discussed above, which are essential to the resolution of standard analytical models. Agent-based models represent the economy as a complex adaptive system in which heterogeneous agents repeatedly interact according to heuristic, that is non-optimized rules (Tesfatsion (2006))[5]. Macroeconomic features do not result from log-linearization near a reference equilibirum but instead *emerge* from these local interactions: agent-based models do have microfundations but do not need strong aggregation assumptions, like in analytical models (Page (2004)). Hence, we are able to explicitly model agents' learning instead of rational or near-rational agents[6] and agents' heterogeneity instead of the representative agent. Agents do not know the underlying structure of the economy, nor the features of the others agents. As a consequence, agents' decisions are not necessary mutually consistent, expectations are not necessarily anchored and markets do not need to clear. Results are obtained through computer simulations as these models do not have any analytical closed-form solutions because of non linearity and randomness in agents' decisions and interactions. To this respect, we also contribute to the use of designs of experiments – a smart sampling method inherited from engineering – for the analysis of economic agent-based models.

Our main results are the following. We highlight the primary role of credibility for macroeconomic stabilization, both in terms of inflation and unemployment. Indeed, a perfectly clear and credible inflation target rules out the trade-off between both objectives. Interestingly, in that case, the meeting of the so-called Taylor principle does not appear as a necessary condition to the stabilization of the economy. Furthermore, we point out two sources of macroeconomic instability when the target is imperfectly perceived by agents: a lack of coordination between individuals, who hold heterogenenous expectations and the lack of coordination between the CB and agents, where private expectations are anchored to a noisy target. In both cases, a trade-off is introduced between both objectives. We are able to draw a parallel between our findings and the debate on the potential welfare cost of public information (`see` more paricutlarly Morris & Shin (2002)). Indeed, we highlight the particularly bad effect of the disclosure of highly imperfect public information. Finally, we show how the lack of credibility produces unanchored and endogeneous expectations, which highly disturb the ability of the CB to react to both demand and cost-push shocks and make the trade-off between both objectives much steeper. Interestingly, even if our results go along the previous findings, we are able to distinguish the sources of bad macroeconomic performances. We also show that unanchored private expectations are enough to disturb the transmission of monetary policy to the economy and in what extent it restricts the Taylor rule influence on macroeconomic stabilization.

The remainder of the paper is organized as follows: section 2 describes the model, section 3 details the setting of the simulations and the sampling device, the main findings

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[4] The use of agent-based models to question macroeconomics issues is rather recent. Contributions include Raberto et al. (2008), Oeffner (2008), Canzian (2009) or Lengnick (2011). To our knowledge, none of them is explicitly related to the analysis of inflation targeting.

[5] *see* the contributions collected in Tesfatsion & Judd (2006). The PhD dissertations of Oeffner (2008) and Canzian (2009) also contain surveys of characteristics and advantages of agent-based modeling for economic analysis.

[6] *see* Brenner (2006) and Kirman (2011) for a statement of learning in agent-based models.

are discussed in section 4 and section 5 concludes.

2 The model

Inflation targeting has been mostly analysed in New Keynesian models (*see* Woodford (2003)). Indeed, they have become the workhorse of the analysis of macroeconomic issues such as the link between money, inflation and the business cycle, or the assessment of alternative monetary policies. These are optimizing and microfounded monetary business cycle models with staggered price setting: they integrate Keynesian ingredients into a real business-cycle-type dynamic general equilibrium apparatus (Gali (2001)). They typically rely on strong assumptions – rational expectations and market clearing, representative agents, complete information. We aim at assessing inflation targeting in a framework which relax these assumptions, but remains close enough to the New Keynesian one to allow for comparisons between both resulting outcomes.

In our model, labor is therefore the only input, there is no capital, just like the baseline New Keynesian model. However, this is a one-single perishable good economy populated by n consumers and *one-single firm*. We indeed decide to sum-up the supply side of the economy by a single monopolistic firm. This choice is motivated by the fact that New Keynesian models are based on monopolistic competition models (see Blanchard & Kiyotaki (1987)). They assume many *identical* firms (which share the same production function and the same mark-up on the marginal cost) and focus on *symmetric* equilibrium. At this equilibrium, all firms sell the same quantities of good at the same price and get the same profit. In such a context, we think that restricting the supply side to one monopolistic firm is a satisfactory modeling device, all the more that our model as well as New Keynesian ones focus on the way the interest rate influences the demand side. Note also that this simplification is a current one in closely related works, for example in Raberto et al. (2008). Other discrepancies between our framework and the usual one will be discussed throughout this section.

We successively describe how aggregate supply and aggregate demand schedules and the resulting outcomes on the good market are set. The different steps are as follows: first, the labor market yields the total amount of hired labor and according to, the good production in the economy, as well as the production costs of the firm and the corresponding labor income of households. The price is set through a mark-up on the marginal cost. Second, households set their good demand in facing a trade-off between consumption and savings. Third, the good market allocates the produced quantities among households, setting the firm's profit and households' utilities. Fourth, a learning mechanism updates the agents' strategies. Fifth, the CB acts as a flexible inflation targeter (in the sense of Svensson (1997)) and sets the nominal interest rate according to the current inflation and unemployment rates. We aim at testing the impact of several expectations scenarios on the performances of monetary policy in this framework.

The following subsections detail each step of the model. Small letters stand for individual variables and capital letters for aggregate ones.

2.1 Setting of the good supply

At the beginning of each period t, each household is endowed with an inelastic one-unit labor supply[7], i.e. $h^s(i,t) = 1$, $\forall i, t$ and a desired nominal wage $w^d(i,t)$. We assume that

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[7] The labor supply of households is fixed whereas there is no such restriction in New Keynesian models. However, this allows to get an explicit definition of unemployment in the model and herewith of the economic situation. Moreover, this restriction is a common one in agent-based macroeconomic models, see for example

households update each period their desired wage according to the expected inflation rate:

$$\begin{aligned} w^d(i,t) &= w^d(i,t-1) \times (1+\gamma_w(i,t)\pi^e(i,t+1)) \text{ if } \pi^e(i,t+1) > 0 \ , \\ w^d(i,t) &= w^d(i,t-1) \text{ else} \end{aligned} \tag{1}$$

where $\gamma_w(i,t) > 0$ stands for the degree of indexation adopted by household i at time t on the inflation rate he expects for the next period, $\pi^e(i,t+1)$ (see sections 2.4 and 2.5.2). According to equation (1), wages are increasing in the expected inflation rate and we assume nominal wage downward stickiness. Other works using this kind of device include Oeffner (2008) and Raberto et al. (2008). It is not specific to New Keynesian models but it creates a direct transmission channel of inflation expectations to labor costs and herewith to the aggregate price. It then stands for the expectations channel of monetary policy.

The firm has a labor demand strategy $H^d(t)$ (see section 2.4 for further details). The labor market confronts the firm with the households, sorted by increasing desired wages. This rationing mechanism is consistent with the fact that the firm is a monopoly, and therefore has a market power. The total amount of hired labor is then given by $H(t) = \min(H^d(t), n)$ and the unemployment rate is computed as:

$$u(t) = \frac{n - H(t)}{n} \tag{2}$$

The corresponding good supply is given by the usual production function (see for example Gali (2008)):

$$Y^s(t) = AH^{1-\alpha}(t) \tag{3}$$

where $\alpha \in [0,1[$ and the technology factor A is set equal to its long-term value, i.e. $A(t) = 1$, $\forall t$ (Woodford (2003, chap. 4)). Each household gets his labor income $w^d(i,t)h(i,t)$, where $h(i,t) \leq 1$ stands for the effective supplied labor. The total production costs are given by $TC(t) = \sum_i w^d(i,t)h(i,t)$ and the aggregate nominal wage by a weighted average of individual ones, i.e. $W = \frac{TC}{H}$. This and the production function (3) yield the firm's marginal cost $\frac{W}{(1-\alpha)}Y^{\frac{\alpha}{1-\alpha}} = \frac{TC}{(1-\alpha)Y^s}$. As the firm is a monopolist on the good market, we assume that it has a market power and sets its price according to a mark-up $\mu \geq 0$ on the marginal cost, i.e. $P = \frac{(1+\mu)}{(1-\alpha)}\frac{TC}{Y^s}$. As soon as $\alpha \neq 0$, the marginal cost is increasing and higher production yields a higher price.

Note that New Keynesian models assume price stickiness in a Calvo (1983) manner, i.e. each period, only a fraction of all firms is able to adjust their price in case of changes in the demand. This creates a nominal rigidity which allows for real effects of monetary policy in the short run. We choose not to integrate such a feature in the model as we already assume nominal rigidity in real wage adjustements (see equation (1)). In our economy, like in the New Keynesian one, the Philips curve – emerging through the relationships between the production, the price level, and the expected inflation rate (see equations (1), (3) and the price setting equation) – incorporates therefore a nomial rigidity.

2.2 Setting of the good demand

2.2.1 Households' incomes

Each household has an initial wealth $b(i,0) = \bar{b}_0$, $\forall i$ and receives then each period a nominal income flow $y(i,t)$ given by:

$$y(i,t) = w^d(i,t)h(i,t) + \frac{\Pi(t-1)}{n} + b(i,t)(1+i_{t-1}) \tag{4}$$

Delli Gatti et al. (2005), Oeffner (2008), Gaffeo et al. (2008) or Raberto et al. (2008). Furthermore, this can be easily interpreted as a full-time job for example.

We assume that households own an equal share of the firm and accordingly each of them receives an equal share of the firm's total profit (positive or negative) from the preceding period, i.e. $\frac{\Pi(t-1)}{n}$. We also assume that households can transfer wealth from one period to the next through one-period maturity bonds: $b(i,t)(1+i_{t-1})$ stands for nominal holdings (positive in case of savings, i.e. $b(i,t) > 0$ and negative in case of debt, i.e. $b(i,t) < 0$) and the corresponding interests. These assumptions are much in line with the New Keynesian baseline models (see again Woodford (2003, chap. 4)). The nominal interest rate i is set by the CB (see below section 2.5)[8]. Note that households get an initial wealth. This is due to the very sequential nature of agent-based modeling, contrary to New Keynesian models which are simultaneously solved: households simultaneously receive profits and labor income and are then able to purchase goods at a higher price than the marginal cost whereas labor incomes exactly correspond to production costs. In our model, at the beginning, households do not have any past profits or interests on past savings yet, and only receive labor incomes. The resulting demand can not absorb all the production at a higher price than the marginal cost. The resulting profits, which are distributed for the next period to households, are small or even negative. This contributes to lower further demand. Considering an initial wealth allows us to avoid this problem.

To keep the model close to the spirit of the Euler equation, which determines the rule for the evolution of the demand in New Keynesian models (see Woodford (2003, chap. 2)), we assume that households smooth their consumption path by estimating their permanent income $\tilde{y}(i,t)$ as defined by Friedman (1957):

$$\tilde{y}(i,t) = (1-\rho)y(i,t) + \rho\tilde{y}(i,t-1) = (1-\rho)\sum_{l=0}^{\infty}\rho^{l}y(i,t-l) \tag{5}$$

where $\rho \in [0,1[$.

2.2.2 Setting of the savings or debt strategy

Each period, households determine the share $k(i,t)$ of $\tilde{y}(i,t)$ they plan to spend in consumption. Just like New Keynesian models (see Woodford (2003, chap. 2)), the trade-off between savings and consumption is driven by changes in the expected real interest rate. To this respect, the share $k(i,t)$ evolves as follows:

$$k(i,t) = k(i,t-1) - \gamma_k(i,t)(i_t - \pi^e_{t+1}(i)) \tag{6}$$

in which we assume that the natural real interest rate is equal to zero. In standard New Keynesian models, it is a function of agents' time preference. Here, there is no explicit time preference because agents are not engaged in intertemporal optimization programs. If $k(i,t) > 1$, household i borrows money to consume more than his estimated permanent income whereas if $k(i,t) < 1$, he saves part of his income to consume it later. The coefficient $\gamma_k(i,t) \in \mathbb{R}$ can be seen as the way household i reacts to the real interest rate he expects (see section 2.4).

The nominal demand for the good of each household i, $c^d(i,t)$ is therefore given by:

$$c^d(i,t) = k(i,t) \times \tilde{y}(i,t) \tag{7}$$

and the corresponding savings or debt $b(i,t)$ by:

$$b(i,t) = y(i,t) - c^d(i,t) \tag{8}$$

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[8] We assume that there is a single public unit which stands for a commercial bank which lends money to households, a government which issues bonds and a CB which sets monetary policy. This simplification is a common one in such kind of models, see for example Raberto et al. (2008) or Oeffner (2008). The distinction is neither explicitly done in standard analytical models.

Note that a household can get a negative income or estimated permanent income at period t if his current income cannot offset negative profit or the interests of his debt. In that case, his demand is set to zero and his negative income is transferred to the next period through a debt. An upper limit $\bar{k} > 1$ to the consumption rate k is imposed in order to avoid excessive debt and bankrupt of households[9]. A lower bound $\underline{k}$ is also set to ensure a minimal subsistence consumption each period.

2.3 The good market

At this stage, both demand and supply of the good have been determined. We assume an efficient rationing mechanism, consistent with the standard assumption of analytical models that households aim at maximizing their utility, derived from their consumption: households are confronted with the firm by decreasing demand. If a household is rationed, he buys bonds with his remaining cash. The firm's profit is given by $\Pi_t = P_t Y_t - W_t H_t$. As the good is assumed to be perishable, remainder stocks are not supplied next period and leads to a lower profit. Inflation π_t is computed as $\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}}$.

2.4 Agents' learning

2.4.1 Households' learning

Households' strategies and transmission channels of monetary policy Just like in New Keynesian models, we assume both interest rate and expectations channels of monetary policy: a switch in the nominal interest rate directly influences the demand through equation (6) and the expected inflation rate influences both the demand (through the expected real interest rate in (6)) and price through production costs (see equation (1)). Households learn how to react on both labor and good markets, i.e. they have a couple of strategies $(\gamma_w(i,t), \gamma_k(i,t))$. This is an intuitive way of modelling the assumption of bounded rationality (Simon (1971)): agents have limited knowledge and cognitive abilities, that is why they are not able to optimize their behaviors. Instead of that, they try to adjust their reactions to the changing environment through a learning process (see below for details). The learning outcomes have important consequences for the monetary policy performances.

On the one hand, as mentioned above, $\gamma_w(i,t)$ is the coefficient of indexation of the desired nominal wage on the expected inflation. Households face a trade-off when choosing it: either they adopt a strong one (typically higher than one) in order to increase their expected *real* wages but may get unemployed (as they are sorted by increasing wage in the labor market), or they choose a low one (lower than one) to be more likely to get employed but may cut their purchasing power. As labor costs directly determine the price level (see section 2.1), equation (1) sets the direct transmission channel of households' inflation expectations to the inflation dynamics. To see that, let us write the price level P and its evolution as:

$$P_t = (1+\mu) W_t H_t^{\alpha} \Rightarrow \pi_t \equiv \frac{\dot{P}_t}{P_t} = \frac{\dot{W}_t}{W_t} + \alpha \frac{\dot{H}_t}{H_t} \tag{9}$$

where $\frac{\dot{X}}{X}$ stands for the growth rate of the variable X. It is in the CB interest that all households coordinate on an one-unit γ_w coefficient and anchor their expectations on the target. Indeed if, moreover, full-employment is reached, $\frac{\dot{H}_t}{H_t} = 0$ and all households get

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[9] In DSGE models, transversality conditions are imposed to avoid explosive dynamics in the bonds processes of households. Such kind of restrictions cannot be set in agent-based models, we therefore add an ad-hoc upper limit to debt each period.

their desired wage. We then have $\frac{\dot{W}_t}{W_t} = \pi^T$, which implies $\frac{\dot{P}_t}{P_t} = \pi^T$ and price grows at the targeted rate.

On the other hand, $\gamma_k \in \mathbb{R}$ represents the way households adjust their consumption/savings trade-off in reaction to a switch in the expected real interest rate. If $\gamma_k(i) > 0$, a rise in the real expected interest rate yields to a decrease in the demand: the substitution effect dominates. This is the usual way by which monetary policy influences the demand through the interest rate. However, households can adopt a negative $\gamma_k(i)$ coefficient. In that case, the consumption share rises if the real interest rate is above its natural level (supposed to be zero here) and the income effect dominates. We must have $\gamma_k > 0$ for the CB to influence the demand in such a way that an increase in nominal interest rate achieves a slowdown in the demand. Note also that high positive values are better as they imply that only small switches in the nominal interest rate lead to large variations of the demand. Moreover, inflation expectations of households have to be coordinated so that switches in the nominal interest rate produce proportional switches in the real expected interest rate. Through coefficient γ_k, we have what we can define as the "aggregate demand channel" of monetary policy.

Updating of households' strategies We assume a social learning mechanism coupled with a random exploration of strategies spaces. This is modeled through an elementary form of genetic algorithm with a roulette-wheel selection[10]. This is the dominant form of learning in economic models and it is well-suited to represent learning in a heterogeneous population of agents with a variety of behaviors, who aim at optimizing an objective in a complex environment. Here, households try to increase their performance, measured with their smoothed utility given by:

$$\tilde{u}(i,t) = (1-\rho)u(i,t) + \rho\tilde{u}(i,t-1) = (1-\rho)\sum_{l=0}^{\infty}\rho^l u(i,t-l) \tag{10}$$

where $u(c(i,t)) \equiv ln(c(i,t))$, $\forall i$[11].

Each period, with a probability P_{imit}, a household imitates a couple of strategies (γ_w, γ_k) of an other agent. The imitation process is designed so that households tend to imitate strategies which yield better performances than their ones: the more utility a household gets, the more likely his couple of strategies is to be imitated by another household. According to that, the probability for a household i to be imitated is given by:

$$\frac{\exp(\tilde{u}(i))}{\sum_{l=1}^{n}\exp(\tilde{u}(l))}. \tag{11}$$

where the exponential function is set to cope with negative utility values.

With a probability P_{mut}, a household can also randomly draw a new couple of strategies. The new γ_w coefficient is drawn in a normal distribution with the mean equal to the population strategies' mean, i.e. the mean of the coefficients γ_w across all households and a given standard-deviation, denoted by σ_{mutW}: $\mathcal{N}\left(\frac{\sum_{l=1}^{n}\gamma_w(l)}{n}, \sigma_{mutW}\right)$. We truncate the draw at zero as negative indexation coefficients do not make any sense. The new strategy γ_k is drawn in a random normal distribution as well: $\mathcal{N}\left(\frac{\sum_{l=1}^{n}\gamma_k(l)}{n}, \sigma_{mutK}\right)$ but this draw allows for negative coefficients. Note that the parameter σ_{mutW} can be interpreted as

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[10] See notably Holland et al. (1989), Sargent (1993) and Brenner (2006) for general statements. Applications to economic issues include for example Arifovic (1995) or Yildizoglu (2002).

[11] Note that in analytical models, households' utility is also a decreasing function of labor but here, labor supply is fixed, even if the effective labor can be below one unit in case of unemployment. It is not, therefore, a strategy of households, in the sense that they cannot act on it to try to increase their objective. That is why we do not include labor in the utility function.

a cost-push shock in standard analytical models such as New Keynesian ones. Indeed, it directly impacts production costs and herewith the price level. As for the parameter σ_{mutK}, it can be interpreted as a demand shock as it directly impacts consumption rates of households and herewith the good demand.

In case of no imitation or exploration, the household keeps his strategies.

2.4.2 Firm's learning

The firm has to choose its labor demand H^d. As we assume a single firm, it cannot benefit from social learning and can only learn through an individual learning process. We consider a simple adaptive mechanism, which is a smooth form of learning, much in the spirit of gradient learning (see for example Leijonhufvud (2006, p. 1631-32) or Delli Gatti et al. (2005) for an application of such kind of rule in a closely related model). As the firm's profit is increasing as the sold quantities of good increase (as soon as $\alpha \neq 0$), the firm rises its labor demand when its profit Π_t is above its trend $\tilde{\Pi}_t$:

$$\text{If } \Pi(t) > \tilde{\Pi}(t) \text{ then } H^d(t+1) = H(t) \times (1+\epsilon) \tag{12}$$

and cuts it when it stands below:

$$\text{If } \Pi(t) \leq \tilde{\Pi}(t) \text{ then } H^d(t+1) = H(t) \times (1-\epsilon) \tag{13}$$

where $\epsilon > 0$ is a parameter which denotes a learning rate. This is an iterative algorithm which proceeds by successive improvements. The smallest ϵ, the smoothest the learning mechanism. The trend of profit is computed as:

$$\tilde{\Pi}(t) = (1-\rho)\Pi(t) + \rho\tilde{\Pi}(t-1) = (1-\rho)\sum_{l=0}^{\infty} \rho^l \Pi(t-l) \tag{14}$$

2.5 Inflation expectations and monetary policy

2.5.1 Setting of monetary policy

The CB acts as a flexible inflation targeter. It sets the nominal interest rate i_t according to a non-linear Taylor (1993) instrumental rule[12] :

$$1 + i_t = (1+\pi^T)\left(\frac{1+\pi_t}{1+\pi^T}\right)^{\phi_\pi}\left(\frac{1+u^*}{1+u_t}\right)^{\phi_u} \tag{15}$$

where π^T stands for the inflation target, u^* for the natural rate of unemployment assumed to be zero and $\phi_\pi > 0$ and $\phi_u > 0$ are the reaction coefficients to inflation and unemployment rates.

2.5.2 Setting of inflation expectations

Each household forms, at time t, his one-step-ahead inflation expectation $\pi^e(i, t+1)$. We assume five different scenarios of inflation expectations, which are supposed to represent different degrees of credibility and precision of the inflation target, and different levels of coordination. Formally, each household sets his inflation expectation according to:

$$\pi^e(i, t+1) = \chi\pi^p(i) + (1-\chi)\tilde{\pi}(t) \tag{16}$$

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[12] We consider the non-linear form because the log-linearized form of the rule is suited when dynamics of the model are kept close to equilibrium. In New Keynesian models, only small disturbances around the rational expectations equilibrium are allowed. Here, the model is non-linear by nature and nothing prevents unemployment and inflation from going very far from the CB's objectives.

where $\pi^p(i)$ corresponds to the perceived inflation target of household i, $\tilde{\pi}$ to the inflation trend computed as a moving average of past inflation rates (exactly as equation (14)) and χ is a parameter between 0 and 1, common across all households. Based on equation (16), Table 1 depicts the way the five different scenarios are obtained.

We define coordination of inflation expectations as a situation where all households hold the same expectation. Moreover, the more precise the communication of the CB is, the closer the perceived target π^p is to the true one π^T. If the target is perfectly clear, i.e. if $\pi^p = \pi^T$, χ denotes its degree of credibility, that is the extent to which inflation expectations are anchored to the inflation target. High values of χ stand for high credibility. Note that it is consistent with the definition of credibility of an inflation target given by Faust & Svensson (2001): credibility is measured as minus the absolute distance between the announced target and the actual private inflation expectations. Here, as χ goes to one, credibility increases.

According to that, scenario 1 is the benchmark case in which the CB perfectly communicates its inflation target and is perfectly credible: households' expectations are therefore fully anchored at the inflation target. Note that this scenario is the closest to the usual New Keynesian setup as it involves that private expectations are consistent with the CB's objectives.

Scenarios 2 and 3 introduce some noise in the CB communication[13]. In both case, ξ stands for the degree of imprecision of the CB's announcement. Moreover, the CB is credible, in the sense that all agents rely on its signal but this signal is not perceived in the same way: in scenario 2, households expectations share the same noisy inflation target, so that expectations are coordinated, whereas in scenario 3, each household has his own perceived inflation target, so that expectations are heterogeneous. Admittedly, the CB perfectly knows its own inflation target and, in case of complete credibility, the announced target should match the true one. However, this noisy target can be interpreted as a proxy for the information the CB communicates as a whole (including its inflation forecasts for example) and this information is mostly noisy (Dale et al. (2011)). This scenario is therefore designed to investigate the consequences of expectations coordination on a wrong signal. We believe that case to be interesting. Indeed, recent contributions (see notably Morris & Shin (2002)) have highlighted the potentially negative role of imperfect public information, as agents tend exclusively to rely on it. This is the case in scenario 2, as we assume $\chi = 1$.

In scenario 3, different perceptions of the CB communication can arise from different sources: divergent points of view in monetary policy committees can contribute to uncertainty and lead to divergent interpretations of the CB communication; CB's annoucements can also be differently perceived by individuals or broadcast by media (see contributions surveyed in Blinder et al. (2008)). In that case, $\xi(i)$ denotes a kind of private noise and individuals hold different expectations.

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[13] `see` Demertzis & Viegi (2009), Ueda (2009) or Lipinska & Yates (2010) for such specifications of noisy signals.

	$\pi^p(i)$	χ	$\pi^e(i, t+1)$	credibility	precision	coordination
1	π^T, $\forall i$	1	π^T, $\forall i, t$	full	perfect	yes
2	$\pi^p \rightsquigarrow N(\pi^T, \sigma_\xi)$, $\forall i$	1	$\pi^T + \xi$, $\forall i, t$	full	noisy	yes
3	$\pi^p(i) \rightsquigarrow N(\pi^T, \frac{\sigma_\xi}{n})$[a]	1	$\pi^T + \xi(i)$, $\forall t$	full	noisy	no
4	$\pi^p = \pi^T$, $\forall i$	$\in]0, 1[$	$\chi\pi^T + (1-\chi)\tilde{\pi}(t)$, $\forall i$	partial	perfect	yes
5	$\pi^p = \pi^T$, $\forall i$	0	$\tilde{\pi}(t)$, $\forall i$	none	perfect	yes

Table 1: The five scenarios of inflation expectations

[a] Both normal draws are truncated at zero to avoid negative perceived inflation targets. In scenario 3, each individual's perceived inflation target is drawn in a normal distribution with mean π^T just like in scenario 2 but with standard deviation equal to σ_ξ/n so that the n draws introduce an equivalent noise in the model as a single draw in scenario 2.

Scenarios 4 and 5 are designed to investigate the lack of credibility of the CB communication, in the sense that households perfectly perceive the inflation target but only partially rely on it. They also take into account past observations to expect future inflation rates. This is consistent with the findings of Roos & Schmidt (2011), who show that backward-looking behavior is a decisisve factor in expectations formation of non-economist people, such as households. Scenario 5 is the nested case of no credibility, where individuals form completely adaptive expectations.

At this stage, the full model has been specified. The next section states the way results of the model are obtained.

3 Simulation protocol

In the model, we focus on the impact of monetary policy according to the way expectations are formed and we focus on the resulting macroeconomic performances. To this respect, we choose to fix all structural parameters of the model at the same level for each scenario. We set $\alpha = 0.25$ (Woodford (2003)) and $\mu = 0.1$ (Rotemberg & Woodford (1998), Woodford (2003)) and $\pi^T = 0.02$, as it corresponds to the target of most CB in developed countries (the ECB or the Bank of England for example). For the other parameters, we do not have any theoretical or empirical references but sensibility analyses have been performed on the whole parameters space of the model during face validation[14]. According to the results, we set $\epsilon = 0.01$, $\bar{b}_0 = 10$, $\bar{k} = 1.5$, $\underline{k} = 0.5$, as those values do not significantly influence the model's dynamics.

We focus on the impact of the remainder parameters. We define three levels of learning, a weak one $(P_{imit}, P_{mut}) = (0.05, 0.01)$, a medium one $(P_{imit}, P_{mut}) = (0.1, 0.05)$ and a strong one $(P_{imit}, P_{mut}) = (0.15, 0.1)$. We set $(\sigma_{mutK}, \sigma_{mutW}) \in [0.05, 0.4]^2$, $(\phi_\pi, \phi_u) \in [0, 2] \times [0, 1]$, $\sigma_\xi \in [0.001, 0.05]$, $\chi \in \{0.1, 0.2, ..., 0.9\}$ and $\rho \in \{0, 0.45, 0.9\}$[15].

We use a *design of experiment* to sample this space of parameters[16]. Large sampling

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[14] Results are not displayed here but are available on request.

[15] The weight of the $t - n^{th}$ period in moving averages of the form (14) is equal to ρ^n. To this respect, $\rho \in \{0, 0.45, 0.9\}$ corresponds to three degrees of backwardness, i.e. naïve behaviors, about few periods backward ($0.45^6 < 1\%$) and many periods backward ($0.9^{45} < 1\%$).

[16] See for example Goupy & Creighton (2007) for a pedagogical statement. This method is widely used in computer simulations in areas such as industry, chemistry, computer science, biology, etc. To our knowledge, Oeffner (2008) and Yildizoglu et al. (2011) are the only applications to an economic agent-based model.

methods such as Monte Carlo simulations come indeed at a computational cost if there are numerous parameters with large experiment domains. We have to launch a huge number of simulations to get a representative sample of all parameters configurations. Designs of experiment allow us to minimize the sample size under constraint of representativity. This method provides a sample, namely a design of all parameters (or factors) configurations. Some properties of the design are useful: space-filling properties, i.e. it has to correctly cover the whole space of parameters; non-collapsing criteria, which ensures that each point is uniquely tested; non-correlation between configurations of parameters, which avoids multicolinearity issues in results' analysis. We use the design proposed by Cioppa (2002), which offers an interesting design regarding these properties. We then launch 17 parameters settings (or experiments, see Appendix A).

Moreover, we randomly initialize agents' strategies: $\gamma_k(i,0) \rightsquigarrow U[0,1]$, $\gamma_w(i,0) \rightsquigarrow U[0.5,1.5]$, $\forall i$ and $H^d(0) \rightsquigarrow U[1,n]$. We also set the initial price level, the initial desired wage and the initial consumption rates of households equal to one. We have $n = 500$ households and $T = 800$ periods[17]. As the model is not deterministic, each experiment is repeated 20 times in order to take into account the randomness of the initialization and the learning process. Each variable is saved every 50 period and we discard the first 100th periods in order to rule out the effects of initialization on the analysis. We then have 5100 data of each response variable in each scenario. The next section compares the resulting outcomes in the five scenarios.

4 Results

Two dimensions play a primary role in the CB's communication: the degree of imperfection and the degree of credibility. We aim at assessing how these two issues affect inflation targeting performances in a learning environment. To this respect, we first describe the model's behavior when the target is perfectly clear and credible (scenario 1). We then assess to what extent introducing noisy communication or partial credibility may cause results to depart from this benchmark, with a particular regard to the influence of the interest rate rule on the achievement of the CB objectives.

Besides some descriptive statistics thoughtout the section, Table 7 in Appendix B displays, for each scenario, the quadratic fit of the (squared) unemployment rate and inflation gap[18] to the coefficients ϕ_π and ϕ_u of the monetary policy rule, controlling for the effects of the learning environment and the degree of noise and credibility. Quadratic fit gives more precise insights into the effects of these coefficients than linear fit does. It allows us to highlight interactions between both monetary policy coefficients on the endogenous variables. Along this line, Figures 2 in Appendix B give the couples of coefficients (ϕ_π, ϕ_u) which have a decreasing or an increasing effect on the objectives. For values of coefficients which have a negative impact on *both* inflation or unemployment, the CB faces no trade-off between its objectives. If some couples of coefficients decrease one objective but increase the other one (either unemployment or inflation), the CB does face a trade-off between both and stabilizes one objective to the expense of the other. We are then able to assess how the way expectations are formed may create or strengthen this trade-off and, herewith, make the conduct of monetary policy more or less easy.

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[17] This is due to computational constraints. Considering a higher number of agents comes at a computational cost. Setting 800 periods avoids numerical explosions in the software, in case of huge inflation rates. Moreover, plots in Appendix B show that it is enough to stabilize aggregate welfare and significantly allow the learning process to take place.

[18] We consider squared variables to express CB's objectives as in standard loss functions (see for example Svensson (1999)).

full sample	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
-0.046*** (4e-09)	0.153*** (<2.2e-16)	-0.056** (0.001)	0.007 (0.667)	-0.09*** (1e-07)	-0.211*** (<2.2e-16)

Table 2: Pearson correlation tests between u^2 and $(\pi - \pi^T)^2$ – (p-value)

4.1 The benchmark case: inflation expectations are well-anchored to the target (scenario 1)

First, Table 3 reports descriptive statistics of agents' behaviors and macroeconomic performances in scenario 1. Inflation is on average equal to 1.74%, which is close but significantly below the target. This can be explained by the indexation strategies of households: althrough close to one, the average indexation coefficient is significantly lower than one unit[19]. As a consequence, nominal wages grow at a rate lower than the target and herewith, the inflation gap is on average negative (see equation (9)). Note also that inflation outcomes exhibit a low volatility. Average substitution coefficients reach a rather high level and remain positive (recall that they are randomly and uniformly initialized between 0 and 1, so that the initial mean is close to 0.5). As stated in the section 2.4, the stronger the substitution coefficients is, the more efficient is the interest rate channel of monetary policy. However, unemployment is on average equal to 9%. This can appear high but this variable displays a particularly strong volatility. Looking in more details, half of the observations actually describes full-employment situations and unemployment rates remain mostly below 8%[20]. The rather high mean is therefore partly due to outliers data.

Second, fit reported in Table 7 in Appendix B provide further insights about these rather good performances in scenario 1. Shocks on the indexation behaviors γ_W, which stand for a kind of cost-push shock, have a positive effect on the inflation gap, but the estimated coefficient is the weakest one over the 5 scenarios. This shows that monetary policy rather well succeeds in stabilizing inflation and unemployment, when inflation expectations are well-anchored to the target. Moreover, the shocks on the substitution behaviors, which stands for demand shocks, do not influence the CB's objectives, suggesting that this kind of shocks is fully offset. Furthermore, as displayed by Figure 2 in Appendix B, reactions to unemployment and inflation are virtually not restricted. As soon as $\phi_\pi > 0.75$ and $\phi_u > 0.4$, inflation gap and unemployment decrease when the reaction coefficients of the rule get stronger. Correlation tests reported in Table 2 confirm that there is no trade-off between both objectives in scenario 1: they are significantly and positively correlated. This obviously makes the conduct of monetary policy much easier.

We first get the following proposition:

Proposition 1 *When inflation expectations are well-anchored to the target, the conduct of monetary policy is made easier, notably in ruling out the trade-off between the inflation and the unemployment objectives. Particularly, hawkish reactions to inflation, that is the meeting of the so-called Taylor principle, does not appear as a necessary condition to the stabilization of the economy.*

Recall that scenario 1 is the closest to the usual New Keynesian model. This finding is then all the more interesting that the so-called Taylor principle is a critical requirement

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[19] T-tests at 5% lead to reject the null hypothesis $\pi(t) - \pi^T = 0$ against the alternative one $\pi(t) - \pi^T < 0$ (t-stat=-9.0953, p-value < 2e-16) and to reject the null hypothesis mean$(\gamma_w(i,t)) = 1$ against the alternative one mean$(\gamma_w(i,t)) < 1$ (t-stat=-7.415, p-value 8.23e-14).

[20] Further descriptive statistics are not reported here but are available on request.

in the usual framework. Indeed, two issues are critical. First, under rational expectations, the baseline New Keynesian model is determinate, i.e. converges to an unique equilibrium path designed to be consistent with the CB objectives, as soon as ϕ_π is sufficiently high, typically higher than 1 (see Woodford (2003)). This is the so-called Taylor principle. Otherwise, the model is indeterminate and can lead to divergent inflation and output gap dynamics. Second, Bullard & Mitra (2002) show that the Taylor principle is a necessary and sufficient condition for this unique equilibrium to be learnable under least squares learning, i.e. for the agents' beliefs to eventually match the true driving process of the economy (the so-called "law of motion"). Otherwise, divergent learning dynamics can move agents' expectations, and herewith inflation and output gap, away from the CB objectives.

Here, in the agent-based model, the issue of macroeconomic stabilization is assessed through the ability of a particular monetary policy rule to keep inflation and unemployment close to their respective targets. To this respect, Proposition 1 shows that the threshold $\phi_\pi > 1$ does not emerge as a critical one, suggesting that the CB can stabilize inflation and unemployment with weaker values of this coefficient. Note that this proposition goes along the lines of several contributions, which put in perspective the importance of the Taylor principle. In the linearized version of the New Keynesian model, Arifovic et al. (2010) assess whether the system can converge to the rational expectations equilibrium, i.e. whether the agents can eventually learn the true law of motion of the economy, through a social learning mechanism modeled with a genetic algorithm. They find that this is mostly the case, even if the Taylor principle is not matched. In an agent-based model, where the CB chooses the monetary policy rule with a genetic algorithm, Delli Gatti et al. (2005) also show that the Taylor principle does not emerge as an evolutionary selected principle. In numerical experiments using the New Keynesain baseline model, Lipinska & Yates (2010) conclude that the performance of the economy is almost invariant to the type of monetary policy rule conducted when the signal of the CB about the inflation target is very precise.

4.2 Impact of imperfect communication (scenarios 2 and 3)

Recall that we assume a single draw of the inflation expectation in scenario 2 with some noise σ_ξ around the true target and the n households share the same inflation expectation. Inflation expectations are then homogeneous and the more noise there is, the further they are from the target. In scenario 3, each household draws his own inflation expectation around the true target with some noise $\frac{\sigma_\xi}{n}$ so that, *average* inflation expectation is equal to the target but inflation expectations are heterogeneous. The more noise, the more scattered they are around the target and herewith, the more heterogeneous they are. Tables 3 and 4 provide descriptive statitics of outcomes in scenarios 2 and 3.

The benchmark scenario clearly exhibits the best macroeconomic performances. All the same, inflation is on average a little closer to the target in scenario 3, probably because indexation coefficients are closer to the unit than in scenario 1. However, inflation in scenario 3 exhibits greater volatility. This suggests that heterogeneity in inflation expectations, even if the average expectations is equal to the target, affects inflation volatility rather than inflation level. Furthermore, unemployment rate is both higher and more volatile. In scenario 2, macroeconomic outcomes are worst than in scenarios 1 and 3, both in terms of level and volatility. Indexation strategies are on average close to one but, as average inflation expectation differs from the target, the resulting inflation stands on average above the target. The substitution effect is particularly lower and more volatile, meaning that the interest rate channel of monetary policy is less efficient in scenario 2.

Fit reported in Table 7 in Appendix B provide further comparison elements. Shocks on indexation behaviors affect both inflation and unemployment in scenarios 2 and 3, and in a stronger way than in scenario 1. Their effects are especially strong in scenario 2, in line with the worse macroeconomic performances we observed. However, note that shocks on substitution strategies do not impact the CB's objectives, either in scenario 2 nor in scenario 3, suggesting that demand shocks are perfectly offset in those scenarios as well. Moreover, looking at the interactions between both coefficients of the Taylor rule, we also see that the situation becomes less easy for monetary policy authorities, especially in scenario 2 (see Figures 2 in Appendix B).

We see that heterogeneity in inflation expectations, even if the average inflation expectation is close to the target, restricts the power of monetary policy on inflation: in scenario 3, only a moderate reaction to unemployment ($\phi_u < 0.7$) achieves a negative and weakly significant effect on inflation. However, note that the fit is rather weak. Monetary policy has a much stronger influence on the dynamics of employment: whatever the reaction coefficient to inflation and if $\phi_u > 0.5$, the unemployment rate falls when the CB reacts in a stronger way. As a consequence, if the reaction to unemployment is rather strong, i.e. $\phi_u \in [0.5, 0.7]$, both objectives move in the same direction, whatever the value of ϕ_π is. Nevertheless, the trade-off between both objectives appears in case of a stronger reaction to unemployment ($\phi_u > 0.7$): unemployment decreases to the expense of inflation stabilization. Note that this trade-off does not appear significantly in the correlation test (see Table 2).

However, in scenario 2, this correlation is significantly negative. Regression results indeed indicate that the CB achieves a significant negative influence on the inflation dynamics through ϕ_π if reaction is not too strong (typically $\phi_\pi < 1.25$), but any reaction to unemployment increases the inflation gap. If the CB is only concerned by inflation, it is in its interest to react in a moderate way to inflation and not to react at all to unemployment (i.e. $\phi_\pi < 1.25$ and $\phi_u = 0$). However, if the CB reacts to unemployment, this increases the inflation gap. The only way to concile both objectives is toreact only to inflation and in a moderate way (i.e. $\phi_\pi < 1$ and $\phi_u = 0$)[21]. The trade-off between both objective is therefore more salient than in scenario 3.

This underlines that two factors can deteriorate the efficiency of monetary policy: i) more heterogeneity in inflation expectations (i.e. the lack of coordination *between individuals*) and ii) the misanchor of expectations (in the sense of a coordination on a point far from the CB's objective, i.e. a lack of coordination *between the CB and individuals*). Nevertheless, macroeconomic outcomes appear better in the first case (scenario 3).

Note that we have analysed performances as a whole, but considering only the experiments in which noise is low, the three scenarios yield to comparable and successful macroeconomic performances[22]. However, as soon as the noise increases, macroeconomic outcomes get worse in both scenarios 2 and 3: inflation gap and unemployment become simultaneously higher and more volatile.

Looking at the variance of agents' strategies allows us to see the link between noise in inflation expectations and heterogeneity in households' behaviors, and herewith macroe-

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[21] Interestingly, here again, the Taylor principle does not emerge as a desirable property of the Taylor rule. In a simulated version of the New Keynesian model, Fukac (2008) finds a similar result: if the CB and the private agents hold divergent inflation expectations, it creates a mismatch between the real interest rate the agents expect, which determines the evolution of the demand and the intended real interest rate, fixed by the CB. In that case, the CB has to react only in a moderate way to inflation, not to magnify the effects of this mismatch on macroeconomic volatility.

[22] In that case, Welch tests at 5% lead not to reject the null hypothesis of means equality of the inflation gap between scenario 1 and 2 (t-stat= -0.1257, p-value=0.9) and scenario 2 and 3 (t-stat=-1.4099, p-value=0.1588). However, the alternative hypothesis of a lower inflation gap in scenario 3 than in scenario 1 cannot be rejected (t-stat=-4.6133, p-value $<$ 2e-16). Concerning unemployment, the three scenarios exhibit significantly equal outcomes: t-stat=-0.7261 (p-value = 0.468) between scenarios 1 and 2, t-stat=0.0196 (p-value = 0.9844) between scenarios 1 and 3 and t-stat=0.5876 (p-value = 0.5569) between scenarios 1 and 2.

	no noise	full sample	level of noise in scenario 2		
	(scenario 1)	(scenario 2)	low	medium	high
$\pi(t) - \pi^T$	-0.0026 (0.0134)	0.0024 (0.0312)	-0.0021 (0.0166)	-0.0028 (0.0369)	0.0144 (0.0463)
$u(t)$	0.0874 (0.2094)	0.1715 (0.3037)	0.0907 (0.2227)	0.1384 (0.2935)	0.2753 (0.3563)
$mean(\gamma_w(i,t))$	0.9451 (0.4041)	0.9831 (0.4143)	0.9952 (0.3909)	1.0246 (0.349)	1.181 (0.4431)
$mean(\gamma_k(i,t))$	0.6574 (0.1998)	0.5876 (0.2703)	0.7052 (0.2554)	0.5095 (0.3331)	0.4578 (0.3154)
$var(\gamma_w(i,t))$	0.0533 (0.0495)	0.0514 (0.0477)	0.0634 (0.0469)	0.0426 (0.0228)	0.0734 (0.059)
$var(\gamma_k(i,t))$	0.0554 (0.0508)	0.0548 (0.051)	0.0714 (0.0471)	0.0534 (0.0473)	0.0601 (0.0529)

Table 3: Mean and standard deviation in brackets of agents' behaviors and macroeconomic performances in scenario 2, according to the level of noise: low ($\sigma_\xi \in [0.001, 0.015]$), medium ($\sigma_\xi \in]0.015, 0.035[$) and high ($\sigma_\xi \in [0.035, 0.05]$).

conomic performances. Note that, in scenarios 1 and 2, where inflation expectations are homogeneous, households' behaviors exhibit quite similar heterogeneity as a whole, whereas this heterogeneity is stronger in scenario 3. Morevover, in scenario 3, the more heterogeneous the inflation expectations are (i.e. the higher noise there is), the more heterogeneous are agents' behaviors. This is especially clear as far as the indexation coefficient is concerned. This can explain why inflation is more volatile in scenario 3 than in the benchmark one. When the noise becomes very high, we also see that both scenarios 2 and 3 exhibit significantly higher heterogeneity in agents' behaviors than in the benchmark scenario. The fact that a link does exist there between noise and heterogeneity of behaviors proves that the negative effect of noise on macroeconomic performances does not arise solely from a purely mechanical effect due to the introduction of more noise in the model.

As a conclusion, we can highlight the following proposition:

Proposition 2 *Macroeconomic instability can arise from two sources:*

1. *Heterogeneity in inflation expectations, i.e. a lack of coordination between individuals.*
2. *The miscoordination of inflation expectations, i.e. a lack of coordination between the CB and individuals.*

In both cases, it restricts the extent to which reaction to inflation gap does achieve its goal and introduces a trade-off: stabilizing unemployment comes at the cost of increasing the inflation gap. It also leads to more heterogeneous agents' behaviors. However, it appears that coordination of expectations on an highly noisy target yields to the worst outcomes.

This result can be related to the debate on the potentially bad effect of transparency in the conduct of monetary policy[23]. Contributions such as Morris & Shin (2002) or Ueda (2009) argue that private agents are likely to focus on public information to form their own expectations. In the case of monetary policy, they completely rely on the CB's

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[23] see Cornand & Baeriswyl (2010) for a review.

	no noise	full sample	level of noise in scenario 3		
	(scenario 1)	(scenario 3)	low	medium	high
$\pi(t) - \pi^T$	-0.0026	-0.0015	-0.0011	-0.0049	0.0016
	(0.0134)	(0.0224)	(0.0113)	(0.0165)	(0.0237)
$u(t)$	0.0874	0.1281	0.0928	0.1194	0.1662
	(0.2094)	(0.2595)	(0.2123)	(0.2617)	(0.287)
$mean(\gamma_w(i,t))$	0.9451	1.0165	0.9876	0.9264	1.1308
	(0.4041)	(0.414)	(0.3249)	(0.3408)	(0.51)
$mean(\gamma_k(i,t))$	0.6574	0.6502	0.707	0.6185	0.6345
	(0.1998)	(0.211)	(0.2089)	(0.1415)	(0.2567)
$var(\gamma_w(i,t))$	0.0533	0.0596	0.0423	0.0639	0.0732
	(0.0495)	(0.0482)	(0.0475)	(0.0236)	(0.0605)
$var(\gamma_k(i,t))$	0.0554	0.0607	0.0602	0.0518	0.072
	(0.0508)	(0.0487)	(0.0468)	(0.0444)	(0.0529)

Table 4: Mean and standard deviation in brackets of agents' behaviors and macroeconomic performances in scenario 3, according to the level of noise: low ($\sigma_\xi \in [0.001, 0.015]$), medium ($\sigma_\xi \in]0.015, 0.035[$) and high ($\sigma_\xi \in [0.035, 0.05]$).

announcements to expect inflation. Therefore, if the disclosed information is noisy, there is a risk that the effects of public noise get amplified and macroeconomic performances get worst. Particularly, i) if the public information is very imprecise in comparison to agents' private information (Woodford (2005) and Svensson (2007), among others) or ii) if private agents are not able to correctly assess the noise in public information (Dale et al. (2011)), the disclosure of public information can be really costly in terms of welfare. If we interpret the common noise ξ in scenario 2 as the noise in public information and the individual noise $\xi(i)/n$ in scenario 3 as the noise in private information, Proposition 2 confirms the above statements. i) Macroeconomic instability is worst when the announced target is highly imprecise regarding the true inflation objective than when individuals hold private but closer *average* inflation expectations to the target. ii) In scenario 2, agents completly rely on the CB information ($\chi = 1$) and are, then, not aware that this information can actually be imperfect.

We now turn to the question of credibility of the inflation target.

4.3 Consequences of partial credibility of the inflation target (scenarios 4 and 5)

Table 5 displays outcomes in scenario 4 (partial credibility of the announced inflation target) as well as the nested cases of full credibility (scenario 1) and no credibility at all (scenario 5). It is plain to see that the less credible the inflation target is, the further macroeconomic outcomes are from the CB's objectives, both in terms of level and volatility. Scenario 5, without any explicit target or any credibility at all, clearly exhibits the worst macroeconomic figures, where more than a quarter of the observations are characterized by both deflation and huge unemployment rates[24].

Surprisingly, in scenario 4, when the target is weakly credible, behaviors patterns are quite close to those emerging in the benchmark scenario, both regarding the average level of substitution strategies and indexation coefficients and their heterogeneity among the

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[24] Again, further descriptive statistics are not given here but available on request.

	level of credibility					
	full cred.	partial	low	medium	high	none
	(scenario 1)	(scenario 4)	(subsets scenario 4)			(scenario 5)
$\pi(t) - \pi^T$	-0.0026	0.0067	0.0155	0.0016	-0.0012	0.0926
	(0.0134)	(0.0624)	(0.1093)	(0.0206)	(0.0228)	(0.1958)
$u(t)$	0.0874	0.1795	0.228	0.1654	0.1275	0.259
	(0.2094)	(0.2968)	(0.3151)	(0.3003)	(0.2621)	(0.3239)
$mean(\gamma_w(i,t))$	0.9451	0.995	0.9647	0.9594	1.056	1.0875
	(0.4041)	(0.4661)	(0.5367)	(0.3554)	(0.494)	(0.5825)
$mean(\gamma_k(i,t))$	0.6574	0.6246	0.6573	0.6085	0.6136	0.5733
	(0.1998)	(0.1964)	(0.203)	(0.1348)	(0.2359)	(0.2668)
$var(\gamma_w(i,t))$	0.0533	0.059	0.0625	0.0426	0.0724	0.0552
	(0.0495)	(0.0469)	(0.0463)	(0.0241)	(0.0584)	(0.0432)
$var(\gamma_k(i,t))$	0.0554	0.0611	0.0721	0.0524	0.0606	0.0586
	(0.0508)	(0.0489)	(0.0462)	(0.0458)	(0.0522)	(0.0489)

Table 5: Mean and standard deviation in brackets of agents' behaviors and macroeconomic performances, according to the level of credibility of the inflation target: none ($\chi = 0$), low ($\chi \in [0.1, 0.3]$), medium ($\chi \in [0.4, 0.7]$), high ($\chi \in [0.8, 0.9]$) and full ($\chi = 1$).

households. Indeed, substitution effects are strong and indexation coefficients are close to one. They therefore exhibit patterns which are consistent with the success of monetary policy. However, macroeconomic outcomes are clearly worse in scenario 4 than in the first one. It is especially the case as far as the unemployment rate is concerned. Inflation gap remains rather close to zero even if the target is not fully credible but exhibits much more volatility. On the contrary, when the target is highly credible, substitution effect decreases, indexation coefficient goes higher than one unit and both behaviors exhibit more heterogeneity. Despite of that, macroeconomic outcomes improve. This indicates that the anchor of inflation expectations to the target is the primary determinant of macroeconomic stability.

This comes from the way expectations are formed without a perfectly inflation target in the model: agents also rely on past inflation trend. Inflation expectations can therefore get unanchored and partly driven endogenously by past inflation. As a consequence, if the inflation rate goes away from the targeted rate ($\tilde{\pi}$ goes away from π^T), inflation expectations go away from π^T. Indeed, agents adaptively expect that future inflation will be far from the target and through the expectations channel, future inflation will actually be far from the target. In the model, as expectations patterns are exogeneously fixed, monetary policy cannot directly influence them. The only way for policy makers to offset the situation is to drive the actual inflation dynamics back closer to the target. Only after that could inflation expectations go back closer to the target. However, results of the fit show that the conduct of monetary policy is made more complicated when the inflation target is partially credible, and even much more in absence of credibility (see Table 7 and Figures 2 in Appendix B).

Indeed, shocks on substitution strategies γ_K do affect both objectives. Moreover, shocks on indexation strategies γ_W strongly impact inflation dynamics. We conclude that partially endogeneous expectations prevent the CB from fully offsetting demand shocks and disturb its ability to react to cost-push shocks. Furthermore, regression results indicate that no value of ϕ_u achieves a decrease in unemployment. Only with strong reactions to inflation coupled with mow reactions to unemployment does the CB stabilize the inflation gap. However, this is done at the expense of unemployment. Tis is confirmed by Table 2, where a negative and significant correlation between both objectives on the whole sample is displayed in scenario 4. This correlation becomes even higher in case of no credibility at all (scenario 5). Figures 2 clearly indicate this trade-off: only a hawkish reaction to inflation coupled with a strong reaction to unemployment decreases the inflation gap. Intuitively, we can imagine that such a strong reaction is necessary to offset endogenous episodes of hyperinflation or deflation, which are created by fully adaptive expectations. However this policy comes at the cost of unemployment, as such values of reaction coefficients clearly contribute to increase the unemployment rate.

We finally get the following proposition:

Proposition 3 *Credibility, measured as the degree of anchor of private inflation expectations to the announced target, appears as the primary determinant of a successful monetary policy, both in terms of inflation and unemployment stabilization. Imperfect credibility produces unanchored and endogeneous expectations, which highly disturb the ability of the CB to react to both demand and cost-push shocks and create a strong trade-off between both objectives.*

Note that the importance of credibility has already been highlighted in many contributions. De Grauwe (2010) notably shows how a CB can make the trade-off between its two objectives easier to face in enhancing the credibility of its explicit inflation target.

Finally, Boxplots 1 in Appendix B confirm the above findings. They show how the aggregate welfare (computed as the sum of individual utilities) evolves in each case. Clearly, the first scenario overperforms the four others, with welfare strongly increasing and stabilizing at a high level. This is an obvious sign of learning in the model. The second, the third and the fourth scenarios also exhibit an increasing trend in welfare. However, more variability remains at the end of the simulations, especially in the second and the fourth ones. The last scenario is clearly worst, in line with the higher unemployment rates we observe.

5 Conclusion

Two issues play a primary role in the CB's communication policy: the degree of imperfection and the degree of credibility of its announcements. Previous contributions have highlighted how noise in public and private information can affect the conduct of monetary policy and, herewith, become welfare-costly. These results have been established in analytical models, notably in the New Keynesian framework, which has become the workhorse for macroeconomic analysis. Moreover, the need for credibility has also been shown in learning models, in which, however, assumptions remain close to those of this main framework. This paper is an attempt to revisit these issues in an agent-based model. This perspective allows us to consider heterogeneous and interacting agents which are engaged in a learning process. This is very in line with the description of inflation targeting as "a framework designed for a world of learning" (King (2005)). Thanks to a simple model, we assess how imperfect information and the lack of credibility of the inflation target may disturb the conduct of monetary policy and the resulting macroeconomic performances. The main findings are as follows:

- When the announced inflation target is perfeclty clear and credible, the conduct of monetary policy is made easier, notably in ruling out the trade-off between the inflation and the unemployment objectives. In this context, the Taylor principle does not emerge as a critical threshold for macroeconomic stabilization.

- Noise in the CB's announcements can lead to: i) heterogeneity in inflation expectations, i.e. a lack of coordination *between individuals* and ii) miscoordination of inflation expectations, i.e. a lack of coordination *between the CB and individuals*. In both cases, it restricts the influence of the Taylor rule and introduces a trade-off between both objectives. The situation becomes clearly worse when agents completely rely on highly noisy public information. This obviously contributes to the recent debate on the need for transparency and the welfare costs of imperfect public information.
- If the inflation target is not completely credible, private expectations get unanchored and endogenously driven by past inflation. It strongly disturbs the ability of the CB to react to both demand and cost-push shocks and creates a strong trade-off between both objectives. We therefore highlight the primary role of credibility in achieving both full-employment and inflation stability, very in line with the findings of recents contributions in macroeconomic learning models.

These promising results demonstrate the interest of the agent-based framework to investigate macroeconomic dynamics and claim for further analysis in such a context.

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Appendix A: Details of the parameters setting

Table 6 gives the values of the parameters explored in the simulations. These values have been generated using the design of experiment proposed by Cioppa (2002). The Excel sheet which provides the corresponding experimental points up to 29 parameters can be found at : http://diana.cs.nps.navy.mil/seedlab/software.html.

Parameters	*level of learning*	ρ	σ_{mutK}	σ_{mutW}	ϕ_π	ϕ_u	σ_ξ/χ
min	0	0	0.05	0.05	0	0	0.001/0.1
max	2	0.9	0.4	0.4	2	1	0.05/0.9
Experiments							
1	1	0.9	0.33	0.18	0.50	0.90	0.029/0.6
2	0	0.45	0.36	0.25	0.00	0.30	0.032/0.6
3	0	0.45	0.07	0.14	1.30	0.80	0.05/0.9
4	0	0.45	0.16	0.40	1.10	0.10	0.038/0.7
5	2	0.9	0.20	0.09	0.60	0.00	0.041/0.8
6	2	0.45	0.18	0.33	0.10	0.80	0.044/0.8
7	1	0	0.40	0.16	1.80	0.40	0.047/0.9
8	1	0.9	0.31	0.38	1.60	0.60	0.035/0.7
9	1	0.45	0.23	0.23	1.00	0.50	0.026/0.5
10	1	0	0.12	0.27	1.50	0.10	0.022/0.5
11	2	0.9	0.09	0.20	2.00	0.70	0.019/0.4
12	2	0.45	0.38	0.31	0.80	0.20	0.001/0.1
13	2	0.45	0.29	0.05	0.90	0.90	0.013/0.3
14	1	0	0.25	0.36	1.40	1.00	0.01/0.3
15	0	0.45	0.27	0.12	1.90	0.30	0.007/0.2
16	1	0.9	0.05	0.29	0.30	0.60	0.004/0.2
17	1	0	0.14	0.07	0.40	0.40	0.016/0.4

Table 6: Design of experiment (typically an Orthogonal Latin Hypercube) for 7 factors/parameters – the last column is irrelevant for scenarios 1 and 5, the values of σ_ξ are used for scenarios 2 and 3 and the values of χ are set in scenario 4.

Appendix B: Further simulations results

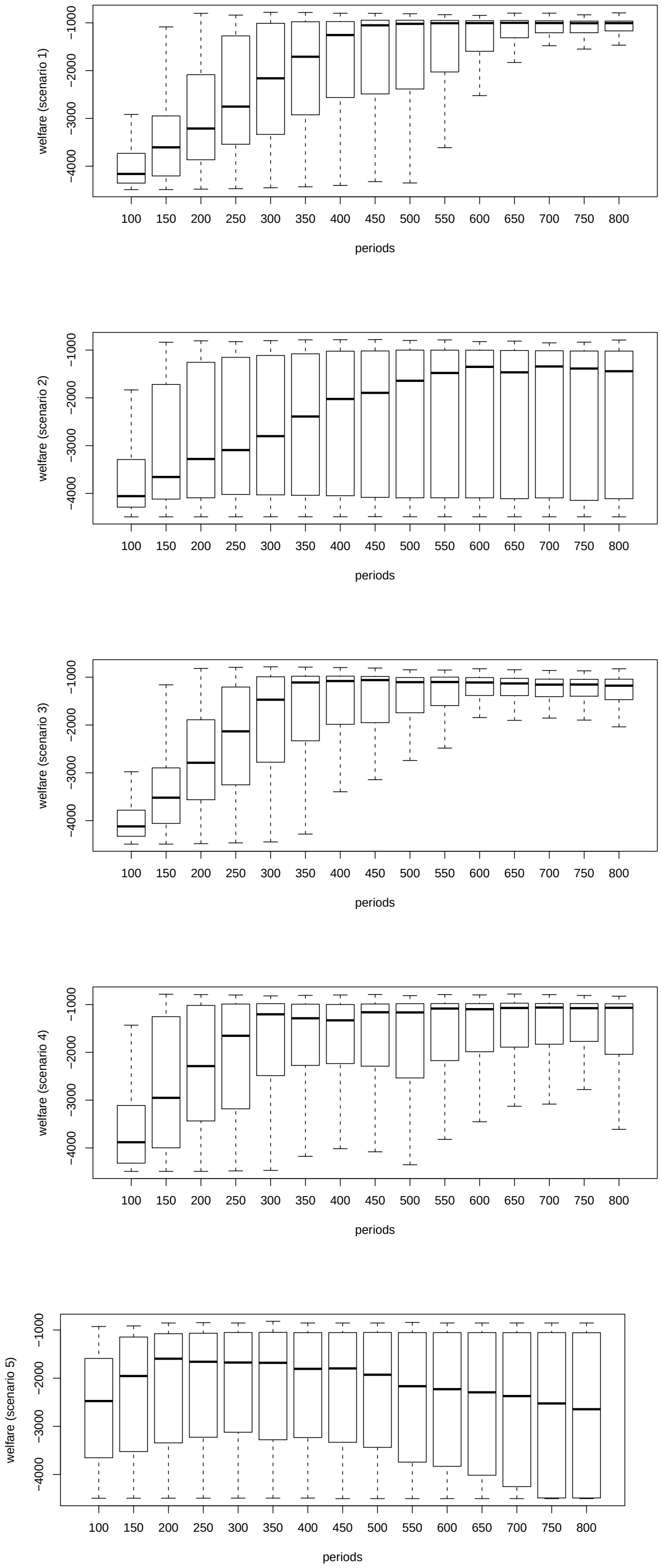

Figure 1: Evolution of the aggregate welfare in the five scenarios – outliers are ruled out.

	scenario 1		scenario 2		scenario 3		scenario 4		scenario 5	
	$infGapSqr$	$unempSqr$	$infGapSqr$	$unempSqr$	$infGapSqr$	$unempSqr$	$infGapSqr$	$unempSqr$	$infGapSqr$	$unempSqr$
(Intercept)	1.3e-04*** (<2e-16)	0.917*** (<2e-16)	0.012*** (7e-08)	0.907*** (<2e-16)	0.002. (0.053)	0.756*** (<2e-16)	-0.018*** (6e-08)	1.448*** (<2e-16)	-0.192*** (9e-10)	1.558*** (<2e-16)
ϕ_π	3e-04*** (2e-08)	-0.017 (0.66)	-0.005* (0.034)	0.009 (0.844)	-3e-04 (0.678)	-0.052** (0.002)	-0.059*** (<2e-16)	0.208*** (8e-06)	0.071*** (1e-06)	-0.102* (0.02)
ϕ_u	4e-04*** (2e-13)	0.116* (0.01)	0.002 (0.227)	-0.057*** (2e-05)	-0.004. (0.09)	0.209*** (1e-06)	-0.208*** (<2e-16)	0.663*** (<2e-16)	0.328*** (<2e-16)	-1.173*** (<2e-16)
ϕ_π^2	-2e-04*** (<2e-16)	-0.025** (0.009)	0.002** (0.007)	-0.043* (0.022)	-2e-04 (0.361)	-0.004 (0.761)	0.015*** (<2e-16)	-0.187*** (<2e-16)	-0.016* (0.025)	0.042* (0.015)
ϕ_u^2	-5e-04*** (<2e-16)	-0.177*** (7e-05)	5e-04*** (0.377)	-0.023 (0.654)	0.003* (0.032)	-0.197*** (3e-07)	0.176*** (<2e-16)	-0.792*** (<2e-16)	-0.283*** (<2e-16)	0.768*** (<2e-16)
$\hat{\beta}_{12}$	1.4e-05 (0.65)	0.076 (0.545)	-7e-04 (0.516)	0.058. (0.08)	-2e-05 (0.962)	0.001 (0.696)	0.064*** (<2e-16)	0.211**** (<2e-16)	-0.058*** (7e-05)	0.184*** (2e-09)
ρ	3e-05** (0.004)	-0.037*** (9e-05)	-0.001*** (<2e-16)	0.014 (0.253)	8e-04** (0.004)	-0.032*** (2e-04)	-0.025*** (<2e-16)	-0.065*** (<2e-16)	0.023*** (3e-04)	0.143*** (<2e-16)
P_{imit}	-0.034*** (<2e-16)	-17.733*** (<2e-16)	-0.263*** (<2e-16)	-21.005*** (<2e-16)	-0.035 (0.353)	-14.816*** (<2e-16)	-2.11*** (<2e-16)	-33.434*** (<2e-16)	1.554. (0.06)	-24.79*** (<2e-16)
P_{mut}	0.031*** (<2e-16)	18.132*** (<2e-16)	0.286*** (<2e-16)	22.01*** (<2e-16)	0.036 (0.356)	15.025*** (<2e-16)	2.443*** (<2e-16)	36.471*** (<2e-16)	-1.377 (0.144)	26.343*** (<2e-16)
σ_{mutK}	-0.089* (0.046)	0.059. (0.094)	-1e-04 (0.914)	0.049 (0.188)	-6e-04 (0.799)	0.039 (0.231)	0.009*** (1e-10)	0.393*** (<2e-16)	0.012 (0.535)	0.133*** (0.001)
σ_{mutW}	9e-04*** (<2e-16)	0.046 (0.163)	0.006*** (<2e-16)	0.565*** (<2e-16)	3e-04. (0.098)	0.081* (0.015)	0.066*** (<2e-16)	0.015 (0.67)	0.234*** (<2e-16)	-0.008 (0.849)
σ_ξ	NA	NA	0.057*** (<2e-16)	2.995*** (<2e-16)	0.015*** (0.001)	0.776*** (3e-04)	NA	NA	NA	NA
χ	NA	NA	NA	NA	NA	NA	-0.023*** (<2e-16)	-0.111*** (1e-12)	NA	NA
F-stat	85.5*** (<2e-16)	35.24*** (<2e-16)	80.32*** (<2e-16)	56.46*** (<2e-16)	4.731*** (3e-05)	36.68*** (<2e-16)	93.96*** (<2e-16)	78.4*** (<2e-16)	34.31*** (<2e-16)	14.86*** (<2e-16)
BP-stat	666 (<2e-16)	715 (<2e-16)	6528 (<2e-16)	117 (<2e-16)	778 (<2e-16)	111 (<2e-16)	215 (<2e-16)	119 (<2e-16)	653 (<2e-16)	383 (<2e-16)
adj. R^2	0.21	0.182	0.162	0.215	0.06	0.144	0.245	0.261	0.105	0.345

Table 7: OLS fit of the squared inflation gap (*infGapSqr*) and unemployment rate (*unempSqr*) in each scenario (p-value).

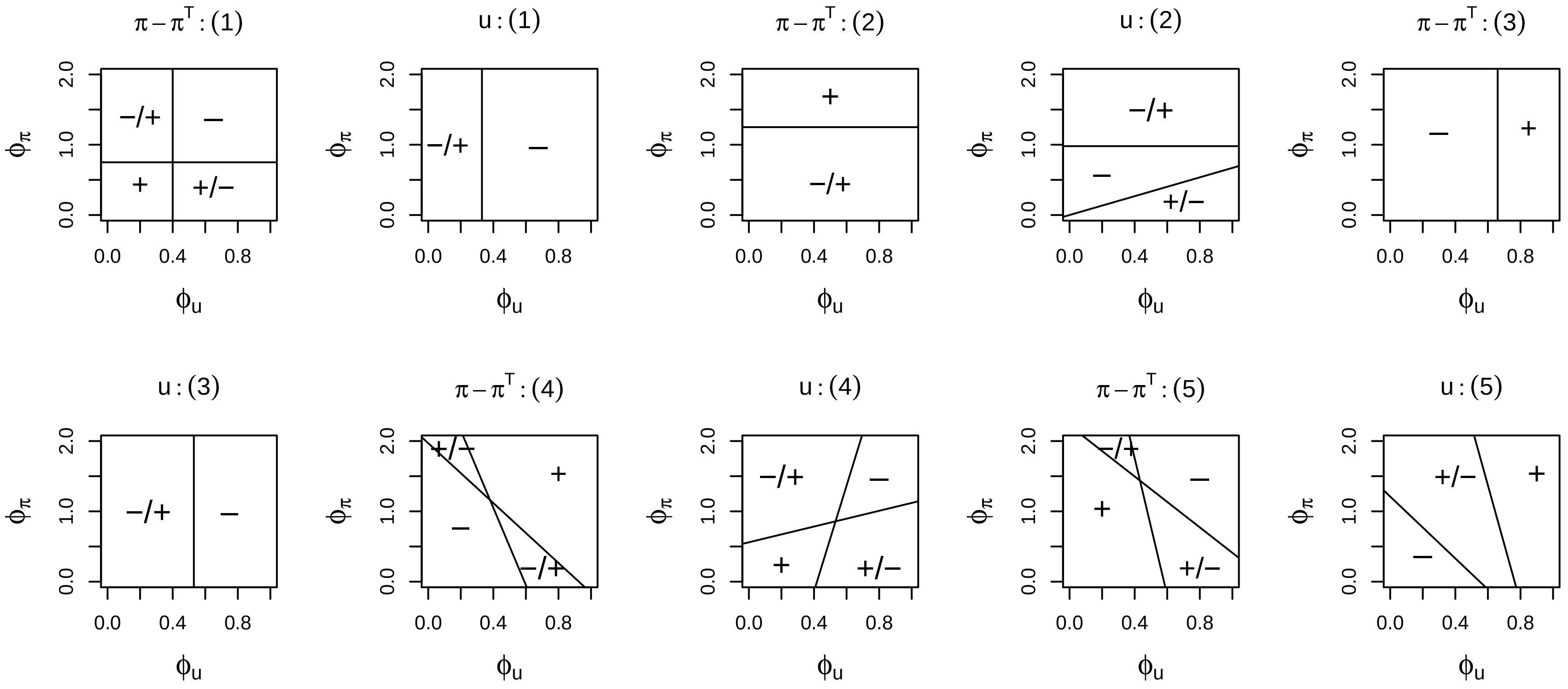

Figure 2: Sign of the estimated derivatives of the squared inflation gap (cf. $\pi - \pi^T$) and the squared unemployment rate (cf. u) with respect to reaction coefficients to inflation and unemployment (ϕ_π, ϕ_u) (corresponding scenario in brackets). "-" indicates that both are negatives, "+" that both are positive, "-/+" that the derivative is negative with respect to inflation coefficient and positive with respect to unemployment coefficient and "+/-" indicates the reverse.