Inflation targeting in a learning economy: an ABM perspective

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Abstract

This paper investigates the performances of an inflation targeting regime in a learning economy framed as an Agent–Based Model (ABM). We keep our ABM as close as possible to the original New Keynesian (NK) model, but we model the individual behaviour of the agents under procedural rationality à la Simon. Accordingly, we assume that their behaviour is guided by simple rules of thumb – or heuristics – while a continuous learning process governs the evolution of those rules. Under these assumptions that also allow the emergence of agents heterogeneity, we analyze the dynamics of the economy without assuming rational expectations, and study the role that a central bank, implementing an inflation targeting regime via a monetary policy rule, can play in the orientation of these dynamics. Consequently, our main goal is to analyse the interplay between the learning mechanisms operating at the individual level and the features and performances of the inflation targeting regime. Our results point to the prime importance of the credibility of central bank's inflation target regarding macroeconomic stabilization, as well as the beneficial role played by that target as an anchoring device for private inflation expectations. We also establish the potential welfare cost of imperfect public information and contribute to the current debate on optimal monetary policy rules under imperfect common knowledge and uncertainty.

Keywords – inflation targeting, agent-based model, central bank communication, expectations, learning.
JEL classification – E52 - E58 - C63 - D83 - D84

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1 Introduction

Ever since the Reserve Bank of New Zealand Act of 1989 introduced inflation targeting (IT) as an official framework for the conduct of monetary policy, IT has been adopted by increasing numbers of countries throughout the world. That development has raised a great deal of interest in that particular monetary regime, both from an empirical and a theoretical point of view.

The present paper aims at contributing to the existing theoretical literature that has, so far, mainly emphasized two kinds of issues concerning IT properties and functioning. First, several studies have investigated how the design of IT could be formulated in terms of a specific policy rule that the monetary authorities would follow (and/or commit to). That strand of the literature has emphasized two families of rules (explicit instrumental rules vs. optimal targeting rules) which have been perceived as two polar ways of implementing IT strategies. In that respect, several contributions have notably assessed the properties of inflation forecast targeting rules (Svensson (1999), Svensson & Woodford (2004)). Second, another strand of the literature has tried to identify the channels through which the IT regime could affect the course of the economy and which features of the economic environment can be key in promoting that impact. The role played by the degree of transparency of the central bank (CB) concerning the conduct of monetary policy has been particularly highlighted in that respect (Walsh (2006, 2008)).

Although those two lines of research pursue different objectives, they both insist on the role of expectations in the functioning of an IT regime and the importance of a declared commitment by the monetary authorities as to the course of their future policy decisions which might anchor those expectations. As such, both lines of research perfectly fit into the new paradigm for monetary policy conduct that has emerged over the past fifteen years. At the heart of that paradigm lies the idea that expectations are the prime concern of CBs, and a key channel of the transmission mechanism. Policy decisions should be transparent, so as to make them predictable and to allow for a more effective monetary policy. In such a context, the CB is viewed as a manager of private expectations (Woodford (2005)).

The New Keynesian canonical macroeconomic model (NK model) has become the reference framework for analysing the design of monetary policy rules under IT and the macroeconomic properties of that monetary regime (see Giannoni & Woodford (2005) for a standard reference). Effectively, the role of agents' expectations are at the core of that dynamic stochastic general equilibrium (DSGE) model, whose main features include forward-looking optimizing behaviour on the part of the private sector and rational expectations (RE), (see Woodford (2003)) for the reference masterpiece in that respect).

However, that theoretical framework does not appear to be totally adequate for addressing transparency and/or communication issues in the analysis of IT regimes. As underlined by Svensson (2009, p. 11), "*in a hypothetical world of a fully informed and rational private sector in a stationary environment with a stationary monetary policy, symmetric information between the CB and the rest of the economy, and rational expectations, there is no specific role for CB communication*"[1]. As a consequence, and to address those issues, deviations from the full RE setting (*i.e.* rational expectation formation based on a complete information set) have been contemplated in the literature, while keeping unchanged, in most of cases, the other underlying ingredients of the NK model. Two modelling routes have been followed in that respect.

The first line of research has reconsidered the common knowledge hypothesis that underlies the computation of the RE equilibrium in the standard canonical NK model. This line, which is inspired by the work of Morris & Shin (2002), has been applied to the analysis of monetary policy transparency in the context of global games and high order beliefs. Acknowledging an imperfect knowledge of monetary policy actions by and within the private sector provides a natural way to analyse the features of the communication policy of the CB and the optimal degree of transparency in a context of public and private noisy signals. For example, Cornand & Heinemann (2008) perform such an analysis by means of a coordination game, while Demertzis & Viegi (2009) address the role of the inflation target as a focal point. Moreover, Baeriswyl & Cornand (2010) and Walsh (2006, 2008) adapt the NK model to an imperfect knowledge environment.

A second line of research replaces the RE setting by an adaptive learning environment: the agents try to learn about the RE (reduced form) equilibrium relationships through a recursive updating of their expectations on the basis of the observations they collect on inflation and output gap variables over time. Based on the new impetus given to the inclusion of learning dynamics in macroeconomics by Evans and Honkapohja (see Evans & Honkapohja (2001)), that line of research has notably been

[1]See also Blinder et al. (2008).

applied to the case of IT by Orphanides & Williams (2005, 2007). Those authors use a NK framework in a context in which the private agents must learn about the model that drives the economy. The announcement of the inflation target affects the learning dynamics and in turn the reaction of the monetary authorities to the economic environment, which favours the convergence to the RE equilibrium. In the same perspective, Eusepi & Preston (2010) consider an adaptive learning process by private agents that is based on a VAR forecasting model which interplays with the other specified relationships stemming from a microfounded NK model. In such a setting, they demonstrate the need for communication on the part of the CB - including the announcement of an explicit inflation target - to prevent the occurrence of self-fulfilling expectational dynamics.

The objective of our paper is to go one - more - radical step forward in the investigation of IT properties under learning, by adopting an alternative approach to model that learning environment. We more particularly address the case of a learning economy, by which we mean not only that the individual agents depart from the RE benchmark when forming their expectations but also, and more fundamentally, that their decisions themselves rest upon a learning mechanism and thus deviate from the optimizing behavioural framework assumption. In other words, we place ourselves in a context in which individual agents are endowed with bounded rationality and are, as a consequence, engaged in a perpetual learning process, using regularly updated heuristics (or rules of thumb) rather than optimally derived rules to take decisions.

Admittedly, bounded rationality and its modelling have had a long history in economics (see the pioneering work by (Simon (1971)) but that concept has been recently brought to the fore by authors who point out the limitations of the NK framework (and, more generally, DSGE methodology) to address macroeconomic issues and, particularly, those regarding the impact of monetary policy (Colander et al. (2008), De Grauwe (2011), Delli Gatti et al. (2010)). One of the most challenging features concerns the cognitive abilities that the agents are assumed to be endowed with (De Grauwe (2011)). In the NK model, agents know and perfectly understand the underlying model of the economy – its structure as well as the values of its parameters. That, coupled with the RE assumption, allows them to use the model structure to make economic decisions and to forecast the evolution of the relevant variables for these decisions[2]. Those information assumptions are, to say

[2] In that respect, the introduction of adaptive learning to substitute for the RE assumption may be

the least, very restrictive and implausible. In general, individuals do not have the ability to process the complexity of the information they receive and to compute optimal action (see Simon (1971)). Rather, they use simple rules, namely "heuristics" to guide their behaviour, in an adaptive way, towards the achievement of their objectives.

Those aspects have been explicitly introduced by Brazier et al. (2008), Canzian (2009) and De Grauwe (2011) using simple evolutionary forecasting heuristics rules within different macroeconomic frameworks: one overlapping-generation model (Brazier et al. (2008)), a simple aggregate model without any microfundations (Canzian (2009)) and a DSGE model (De Grauwe (2011)). All those contributions provide interesting insights about the way an explicit inflation target can overcome the additional macroeconomic volatility caused by a strong departure from the RE setting. Bounded rationality is however modelled only at the level of the expectation formation process while, in most cases, the decision rules are left consistent with the substantive rationality approach .

In the present paper, we aim at overcoming that methodological hiatus by explicitly modelling the learning economy as a complex adaptive system whose functioning and dynamics are primarily based on the adoption by boundedly rational households and firms of *individual, learning-based, "heuristic" rules of behaviour.* Given those modelling assumptions, the DSGE framework and tools have to be replaced by an alternative theoretical apparatus that could deal both with the interaction of individual decisions and the aggregation of the ensuing forms of heterogeneous behaviour in a flexible way. Effectively, we cannot suppose that those aspects would be (implicitly or explicitly) solved in a market clearing, equilibrium situation with RE as we cannot assume beforehand that such a situation would emerge from the functioning of the economy as has been specified here.

In our case, the change in the analytical framework is achieved through the building of an agent-based model (ABM)[3]. Basically, an ABM consists of a simulated

considered as a first step in modelling bounded rationality. However, its introduction, at least in the macroeconomic literature, comes over as a relatively small deviation from the RE hypothesis, as the agents are supposed to know the features of the model of the economy even if they have to learn about the parameters of the equations that make up that model, under the restriction that the economy stays in the neighbourhood of the RE equilibrium. For a learning process based on a misspecified representation of that model, see Evans (2005). Furthermore, in that case, learning usually operates at the aggregate level of the reduced forms of the model.

[3]See the contributions collected in Tesfatsion & Judd (2006). ABM are widespread in several scientific fields other than ones that pertain to social sciences (such as biology or climate change studies). The use of ABM to analyse macroeconomic issues is rather recent. Contributions include Raberto et al. (2008),

artificial economy, in which heterogeneous agents repeatedly interact according to heuristic, *i.e.* non-optimized, rules of behaviour (Tesfatsion (2006)). Those rules can be updated through specified learning process [4]. In addition, due to the bottom-up approach that underlies their construction, ABMs constitute a flexible tool to deal with heterogeneity and allows, on that basis, for the emergence of macroeconomic dynamics or features departing from the RE equilibrium paths that are usually envisioned in the NK model. However, as stressed by De Grauwe (2011), in order to avoid the "everything becomes possible" criticism, that heuristics modelling has to be framed by disciplining devices with respect to the design of decision rules. That is why, in our case, we choose to keep the basic structure of our model very close to that of the NK model. That proximity lends in turn to a natural robustness exercise concerning the results that have been obtained within the NK modelling framework on the properties of IT under learning. We also retain a simple evolutionary mechanism that guides the social learning process of the agents (see Sargent (1993), Arifovic (1995)).

In that respect, the objective of this paper is twofold. First, it aims at providing an original, theoretical framework for a learning economy whose functioning is rooted in the boundedly rational behaviour of individual agents. Second, it seeks to address the impact of an IT regime on the working of that economy. In particular, we try to identify how the anchoring mechanism that the inflation target can provide under that regime, actually manifests itself in that economy and the role that the transparency and credibility of the CB play in that respect.

Our main results may be presented as follows. First, we show the primary role that the credibility of the inflation target plays in the achievement of both monetary policy objectives (whether with respect to inflation or unemployment). When the CB's inflation target is perfectly credible, the dynamics of the economy, which is governed by the learning process of the agents, displays the strongest convergence with respect to those objectives. Interestingly, the so-called Taylor principle does not appear to be a necessary condition for that kind of dynamics to appear. By contrast, the lack of credibility produces unanchored and endogenous expectations dynamics, wich significantly disturb the ability of the CB to stabilise that economy, especially when the volatility of the learning environment is significant. In that

Oeffner (2008), Canzian (2009) or Lengnick (2011). To our knowledge, none of those contributions are explicitly related to the analysis of IT.

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

case, we can observe a sharp trade-off regarding the inflation target *versus* the real economic objective.

Second, when the communication of the CB about the target is inaccurate, our findings echo the debate that has arisen in the literature on the optimal degree of CB transparency in an imperfect public information environment (see more particularly Morris & Shin (2002), Svensson (2007), Dale et al. (2011)). We notably emphasize the welfare cost of the disclosure of highly imperfect public information.

In our model, the inaccuracy of the communication on the inflation target generates two potential sources of macroeconomic instability. One is related to a lack of coordination between individuals, who consequently hold heterogeneous expectations; the other is driven by the lack of coordination between the CB and the agents, when private expectations and the CB's target diverge. Both of those coordination failures strongly disturb the learning process and in turn the ability of the CB to stabilise the economy. The unanchoring of private expectations is the main source behind disruption of the transmission of monetary policy to the economy.

The remainder of the paper is organized as follows: Section 2 describes the ABM of the learning economy adopted in our analysis. We also detail how we evaluate in that setting the macroeconomic impact of IT through the specification of alternative scenarii for the formation of inflation expectations by the private sector. Section 3 details our simulation protocol and the experimental design we use to generate the results. Unlike most of the analyses that use the NK model as a framework, ABMs do not rely upon any analytical closed-form solutions because of non linearity and randomness in agents' decisions and interactions and the non ergodicity of the resulting dynamic system. As a consequence results are obtained through computer simulations. In order to frame that simulation exercise, we use the *designs of experiments* approach – a smart sampling method inherited from engineering – which allows for an exploration of the model parameters' space in a very parsimonious way, unlike Monte Carlo simulations. The main findings are discussed at length in Section 4. We organise the discussion around the two-fold role played by the inflation target within the IT regime: as a coordinating/anchoring device with respect to the private sector's inflation expectations and as a credibility device for the CB regarding the price stability objective of monetary policy. Section 5 concludes.

2 Modelling a learning economy with an ABM

The internal logic of the modelling strategy we adopt in this paper is very different from that of the DSGE models. ABMs are sequential by nature, and the sequence of events has to be described step by step. In DSGE models (including the NK model), agents' decision problems (and the equations used to depict them) are generally solved simultaneously under the assumption of a market clearing general equilibrium process. Nevertheless, we have kept the structure of the ABM deliberately very close to that of the NK model, to allow for comparisons between the outcomes stemming from both frameworks: our ABM is a simple aggregate demand-aggregate supply economic model augmented with a Taylor rule, in which the good market operates under imperfect competition, and price/wage adjustments are characterised by nominal rigidities. The sequence of events for each period is as follows:

1. The firm determines its labour demand, while each household supplies labour and sets its reservation wage. Except for the initial period, those decision variables directly stem from learning and inflation expectations of agents (see Step 6).
2. Households and the firm meet on the labour market. When all feasible transactions have taken place, the quantity of labour hired by the firm, as well as the amount of labour actually supplied and the associated wage bill are determined.
3. The firm uses the quantity of hired labour to produce the consumption good, and sets its price using a mark-up rule. Each household computes its total income (by summing labour and financial income). Each household then chooses the level of desired consumption (and thus its savings or debt strategy).
4. Supply and demand are confronted on the good market: the effective level of consumption is determined.
5. The CB sets the nominal interest rate through a Taylor rule, based on the inflation rate taken as a deviation from the target and on the unemployment rate.
6. Eventually, both agents – the firm and households – update their strategies through learning.

In the remaining of this section, we present theemploir model. First, we specify the behaviour and the learning process of the n households and the firm (see Subsections 2.1 and 2.2). Second, we describe the monetary policy rule and how households form their inflation expectations (see Subsections 2.3 and 2.4). Next, interactions on the labour and good markets are specified (Subsection 2.5). Finally, the main features of the resulting economic dynamics and the transmission channels of monetary policy are discussed (Subsection 2.6).

2.1 Households

The economy is populated by n households, indexed by i, $i \in [\![1, n]\!]$[5].

Labour supply Each household is endowed with an inelastic labour supply normalized to one for each period, i.e. $h^s_{i,t} = 1$, $\forall t, i$. That allows unemployment to be explicitly defined in the model. That type of restriction is a common one in agent-based macroeconomic models (see, for example, Delli Gatti et al. (2005), Oeffner (2008), Gaffeo et al. (2008) or Raberto et al. (2008)) and could be easily interpreted as a full-time occupation.

Our model is characterised by radical uncertainty, in which future paths of relevant variables cannot be given by standard probability laws. Information is only local, and agents are not aware of other agents' characteristics and decisions. Consequently, households' behaviour cannot be described through the usual intertemporal utility maximisation and corresponding first order conditions. In particular, households are not capable of optimally dealing with the trade-off between labour and leisure, which would give rise to an optimal wage rate; nor are households able to derive an optimal consumption path given by the usual first order conditions of the utility maximisation programme (Euler relation). We therefore assume that households use two simple behavioural rules that are updated as they learn more about their environment. The first rule concerns the adjustment of their reservation wage; the second one relates to the level of desired consumption (or their savings or borrowing strategy).

For every period t, each household i sets its reservation wage according to the

[5] Small letters stand for individual variables, and capital letters for aggregate ones. Supply and demand variables are respectively indicated by s- and d-superscripts.

rule:

$$w_{i,t} = w_{i,t-1} \times (1 + \mathbb{1}_{(\pi^e_{i,t+1}>0)} \gamma^w_{i,t}.\pi^e_{i,t+1}) \tag{1}$$

where $\gamma^w_{i,t} > 0$ stands for the degree of indexation that household i sets at time t on the inflation rate it expects for the following period, $\pi^e_{i,t+1}$ (both determined below). Heuristics (1) indicates that the desired wage is increased only if the expected inflation rate is positive. In that case, households raise it by $\gamma^w_{i,t}.\pi^e_{i,t+1}$; otherwise, they keep it unchanged. Wages increase according to the expected inflation rate, while assuming nominal wage downward stickiness. Other works, using that assumption include Oeffner (2008) and Raberto et al. (2008). Although not an explicit ingredient of NK models, that assumption introduces a direct transmission channel of inflation expectations to labour costs and, hence, to price level. That mechanism constitutes the expectations channel of monetary policy (which we further document in Section 2.6). In accordance with that behavioural rule, coefficient $\gamma^w_i \geq 0$ is one of households' two strategies.

Consumption For each period, households also determine the income share $k_{i,t}$ they plan to spend in consumption. The good demand (in real terms) of each household i, $c^d_{i,t}$ is therefore given by:

$$c^d_{i,t} = k_{i,t}.\tilde{y}_{i,t} \tag{2}$$

where $\tilde{y}_{i,t}$ corresponds to its permanent income as defined by Friedman (1957, Chap. III):

$$\tilde{y}_{i,t} = (1-\rho)\frac{y_{i,t}}{P_t} + \rho\tilde{y}_{i,t-1} = (1-\rho)\sum_{l=0}^{t}\rho^{t-l}\frac{y_{i,l}}{P_l} \tag{3}$$

$\rho \in [0, 1[$ is a memory parameter common to all agents, P_t the price level and $y_{i,t}$ the nominal income flow the household i receives for each period:

$$y_{i,t} = w_{i,t}h_{i,t} + \frac{\Pi_{t-1}}{n} + b_{i,t-1}(1 + i_{t-1}) \tag{4}$$

$\frac{\Pi_{t-1}}{n}$ is a share of total profits in the economy from the previous period, $b_{i,t-1}$ represents nominal holdings (positive for savings and negative for debt) and i_t is the nominal risk-less interest rate set by the CB (see Section 2.3). The variable $h_{i,t}$ is the labour that household i effectively supplies to the firm at its desired nominal wage $w_{i,t}$ for time t (see Equation (1)). It should be noted that $h_{i,t} \leq h^s_{i,t}$, since households can be rationed on the labour market (see Section 2.5). Finally, and considering their desired level of consumption $c^d_{i,t}$, the amount of nominal (desired) savings or indebtedness $b_{i,t}$ is given by:

$$b_{i,t} = y_{i,t} - c^d_{i,t}.P_t \tag{5}$$

In Behavioural Rule (2), we assume that households are concerned with smoothing their consumption path (with respect to current income streams), in the spirit of the Euler equation, which determines consumption evolution in NK models (see Woodford (2003, Chap. 2)). Furthermore, if $k_{i,t} > 1$, household i borrows money to consume more than its income, and if $k_{i,t} < 1$, it saves part of its income to be consumed later. Note that agents face a budget constraint, which is not an intertemporal one, but a flow budget constraint, as agents are not able to plan their spending over an infinite horizon[6].

The consumption share of household i, $k_{i,t}$, depends on the gap between the real interest rate it expects, i.e. $i_t - \pi^e_{i,t+1}$ and the natural level (defined below) r^n_t, *i.e.* :

$$k_{i,t} = k_{i,t-1} - \gamma^k_{i,t}(i_t - \pi^e_{i,t+1} - r^n_t) \tag{6}$$

Heuristic (6) is the counterpart of the usual Euler relation in the ABM, which allows us to obtain an "aggregate demand" channel (or consumption channel) for monetary policy. That point is further discussed below (see Section 2.6). The adjustment coefficient $\gamma^k_{i,t} \in \mathbb{R}$ represents households' second strategy.

Households' learning The indexation strategy $\gamma^w_{i,t}$ and the substitution strategy $\gamma^k_{i,t}$ are updated for each period, reflecting the assumption that agents continually adapt their rules through a perpetual learning process (Orphanides & Williams (2005)). We assume a social learning mechanism (imitation) coupled with a random exploration of the space of strategies. ABMs which take into account the learning of agents do, very frequently, adopt a similar representation of learning[7]. That is well-suited to represent learning in a heterogeneous population of agents, who aim

[6] In DSGE models, transversality conditions are imposed to avoid explosive dynamics in bond process. Such restrictions cannot be set in our model, in which we have to impose period-by-period constraints. In that respect, we impose an upper limit $\bar{k} > 1$ to consumption rate k, in order to rule out excessive debt and household bankruptcy, and we impose a lower bound $\underline{k} > 0$ to ensure minimal subsistence consumption for each period.

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

to adapt their behaviour to the evolution of their environment. That adaptation is based on their performance, measured through their smoothed utility:

$$\tilde{u}_{i,t} = (1-\rho)u_{i,t} + \rho\tilde{u}_{i,t-1} = (1-\rho)\sum_{l=0}^{t}\rho^{t-l}u_{i,l} \tag{7}$$

where $u(c_{i,t}) \equiv ln(c_{i,t})$, $\forall i$, and the use of a smoothed measure denotes a concern for the persistence in the performances.

For each period, with a probability P_{imit}, a household imitates a pair of strategies (γ^w, γ^k) of another agent: the higher the performance of a household is, the more likely its pair of strategies is to be imitated by another household. Accordingly, the probability of household i being imitated is given by:

$$\frac{\exp(\tilde{u}_i)}{\sum_{l=1}^{n}\exp(\tilde{u}_l)} \tag{8}$$

where the exponential function is set to cope with negative utility values. That learning mechanism hence favours the diffusion of the most successful strategies among agents.

With a probability P_{mut}, a household can also perform a random experiment, and draw a new γ^w coefficient from a normal distribution with the mean equal to the mean of the coefficients γ^wacross all households, and a given standard-deviation, denoted by σ_{mutW}: $\mathcal{N}\left(\frac{\sum_{l=1}^{n}\gamma_l^w}{n}, \sigma_{mutW}\right)$. We truncate the draw at zero, as negative indexation coefficients do not make any sense. The new strategy γ^k is also drawn from a random normal distribution, with a given standard deviation $\mathcal{N}\left(\frac{\sum_{l=1}^{n}\gamma_l^k}{n}, \sigma_{mutK}\right)$, but that draw does allow for negative coefficients (see Section 2.6). Parameters σ_{mutK} and σ_{mutW} stand for a measurement of variability in the learning process; that variability feeds back into the macroeconomic dynamics (see Section 2.6). In the case of no imitation nor random experiment (i.e. with a probability $1-P_{imit}-P_{mut}$), the household keeps its past strategies.

2.2 The firm

In our model, as in the baseline NK one, labour is the only input; there is no capital. We assume here a monopoly producing a perishable good, but that discrepancy with the usual monopolistic competition assumption of the NK framework (see Blanchard & Kiyotaki (1987)) turns out to be a minor one. That NK framework involves many firms, but they are identical (they share the same production function and the same mark-up on the marginal cost), and the analysis only considers a symmetric equilibrium. In such a context, considering a single firm is not really restrictive, given the objective we give to our model. It should be noted that macroeconomic ABMs commonly make that assumption: for example, in Raberto et al. (2008).

Production, price and profit When the labour demand of the firm (resulting from its learning process, see below) meets the labour supply of the households on the labour market (see section 2.5), the rationing mechanism determines the effective quantity of labour (H_t) that the firm hires, and the corresponding wages that it pays to the hired households. The firm uses this labour to produce the good, through a usual production function (see, for example, Gali (2008)):

$$Y_t^s = A_t H_t^{1-\alpha} \tag{9}$$

where $\alpha \in [0,1[$ encompasses decreasing returns, A_t is the technology factor. The only production costs of the firm result from the wage bill:

$$\Psi(Y_t^s) = \sum_{i=1}^{n} h_{i,t} w_{i,t} \tag{10}$$

and we can compute the nominal aggregate wage level, as a weighted average of individual wages, i.e. $W_t \equiv \frac{\Psi(Y_t^s)}{H_t}$.

Thanks to its market power, the firm sets its price P, according to a mark-up μ on the marginal cost given by:

$$\Psi'(Y_t^s) = \frac{W_t}{(1-\alpha)} \frac{Y_t^s}{A_t}^{\frac{\alpha}{1-\alpha}} = \frac{\Psi(Y_t^s)}{(1-\alpha)Y_t^s} \tag{11}$$

The resulting price is:

$$P_t = \frac{(1+\mu)}{(1-\alpha)} \frac{\Psi(Y_t^s)}{Y_t^s} \tag{12}$$

and it is an increasing function of the production Y^s as soon as $\alpha > 0$.

The rationing mechanism on the good market (see section 2.5) determines the quantity that the firm effectively sells to the households (Y_t), which gives the corresponding profit of the firm:

$$\Pi_t = P_t Y_t - \Psi(Y_t^s) \tag{13}$$

As for households, the firm has only a limited knowledge of the problem it faces: notably, it does not know the demand on the good market it is confronted with, because it is not capable of anticipating all the individual demands $c_{i,t}^d$. We assume that the good is perishable. Consequently, the firm has to learn to set its labour demand facing a three-fold constraint: on the labour market, the total amount of labour supply is limited to n units (one per household), the demanded wages can become quite high, and, on the good market, the firm can be constrained by demand.

Firm's learning As for the households, the firm is also engaged in a learning process. We express its supply strategy in terms of a labour demand strategy[8] H_t^d. The firm aims at gradually adjusting its strategy H^d to the behaviour of the households and the rationing on the markets. As we assume a single firm, it can only benefit from an individual learning process. We consider a simple adaptive mechanism, that is a smooth form of learning, much in the spirit of gradient–ascent learning (see, for example, Leijonhufvud (2006, pp. 1631-32) or Delli Gatti et al. (2005)). The firm increases its labour demand when its profit is above a trend $\tilde{\Pi}_t$, representing its "normal" profits, and it decreases it, if not. We therefore assume the following heuristic adjustment rule:

$$\text{If } \frac{\Pi_t}{P_t} \geq \tilde{\Pi}_t \text{ then } H_{t+1}^d = H_t \times (1+\epsilon) \tag{14}$$

$$\text{If } \frac{\Pi_t}{P_t} < \tilde{\Pi}_t \text{ then } H_{t+1}^d = H_t \times (1-\epsilon) \tag{15}$$

where $\tilde{\Pi}$ is a moving average computed in a similar way as for the permanent income or utility trend, and $\epsilon > 0$ is a parameter which denotes an adjustment rate. That is an iterative algorithm which proceeds by successive improvements. Smaller ϵ depict a smoother and slower learning mechanism.

It should finally be noted that NK models assume price stickiness in a Calvo (1983) manner, i.e. for each period, only a given number of firms are able to adjust their prices in case of changes in the demand. This creates a nominal rigidity which allows for real effects of monetary policy in the short run. Our model already contains such a rigidity in the nominal wage adjustment process (see Equation (1)).

[8] Having a labour demand or a good supply strategy is equivalent from the firm's point of view, as labour is the only input (see Equation (9)). Once the mark-up price has been set, any subsequent price adjustments correspond to quantities adjustments, so that the firm has actually only one decision-making variable, expressed here in terms of labour demand.

Furthermore, the firm's learning process already implies that the firm does not optimally adjust the good supply and, hence, the price, when facing changes on the demand side. The point here is that, in our economy, as in the NK one, the Philips curve – emerging through the relationships between production, price level, and the expected inflation rate (see Equations (1), (9) and (21)) – does incorporate a nominal rigidity.

2.3 Monetary policy rule

The CB, which acts as a flexible inflation targeter, reacts to both inflation and the level of activity, and sets the nominal interest rate i following a non-linear Taylor (1993) instrumental rule:

$$1 + i_t = (1 + \pi^T)(1 + r_t^n) \left(\frac{1 + \pi_t}{1 + \pi^T} \right)^{\phi_\pi} \left(\frac{1 + u^*}{1 + u_t} \right)^{\phi_u} \tag{16}$$

where π^T stands for the inflation target, u^* for the natural rate of unemployment, and $\phi_\pi > 0$ and $\phi_u > 0$ are the reaction coefficients to inflation and unemployment rates in the rule. Parameter ϕ_u relies on the unemployment rate as a target variable, as we are able to explicitly derive its value from the model. Other contributions using that activity level measurement notably include Orphanides & Williams (2007). We consider the non-linear form of the rule, because the log-linearised form is suited to cases in which inflation and unemployment dynamics are kept close to their objectives but, in our case, the model is non-linear by nature, and dynamics may strongly depart from those values.

We now explain how households perceive the monetary policy and form their inflation expectations in the model.

2.4 IT and inflation expectations

Each household forms, at time t, its one-step-ahead inflation expectation $\pi_{i,t+1}^e$. We assume five different scenarii for the formation of inflation expectations. Those scenarii allow us to incorporate three critical components of IT: the credibility and precision of the inflation target and coordination of inflation expectations.

Formally, each household forms its inflation expectation as a weighted average

	π_i^p	χ	$\pi_{i,t+1}^e$	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 [a]	$\pi_i^p \rightsquigarrow N(\pi^T, \frac{\sigma_\xi}{n})$	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 scenarii of inflation expectations

[a] Both normal draws are truncated at zero, in order 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, as in Scenario 2 but with standard deviation equal to σ_ξ/n, so that those n draws introduce a noise in the model that is equivalent to a single draw in Scenario 2.

of its perception of the inflation target (π_i^p) and past inflation trend ($\tilde{\pi}_t$), i.e.:

$$\pi_{t+1}^e = \chi \cdot \pi_i^p + (1-\chi) \cdot \tilde{\pi}_t \tag{17}$$

The weight parameter χ ($\chi \in [0,1]$) is assumed to be common across all households, and may be interpreted as the degree of credibility of the target, i.e. the extent to which inflation expectations are anchored to the (perceived) inflation target. That definition is consistent with the one given by Faust & Svensson (2001), according to which credibility is measured as negative of the absolute distance between the announced target and the actual private inflation expectations. Here, as χ goes to one, credibility increases.

The households can perceive the inflation target with an error: $\pi_i^p = \pi^T + \xi_i$, $\xi_i \rightsquigarrow \mathcal{N}(0, \sigma_\xi^2)$. The precision of the inflation target hence depends on the noise ξ_i: if σ_ξ^2 is high, the true target is highly imprecisely perceived, potentially yielding a value for π_i^p far from π^T the announced target. If $\sigma_\xi^2 = 0$, the target is perfectly clear and $\pi^p = \pi^T$. We further define the particular case of perfectly coordinated inflation expectations as a situation in which all households hold the same expectation, i.e. $\xi_i = \xi$, $\forall i$, and $\pi_{i,t+1}^e = \pi_{t+1}^e$, $\forall i$. Based on Equation (17) and the definition of π_i^p, Table 1 depicts five different scenarii that we retain in our analysis.

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 to the inflation target. That scenario is the closest to the usual NK setup as private expectations are consistent with the CB's objectives.

Scenarii 2 and 3 introduce noise in the CB's communication[9] and, in both cases,

[9] See Demertzis & Viegi (2009), Ueda (2010) or Lipinska & Yates (2010) for such specifications of noisy

σ_ξ^2 stands for the degree of imprecision of the CB's announcement. Moreover, in those scenarii, the CB is credible, in the sense that all agents rely on its signal, but that signal is not perceived in the same way: in Scenario 2, households share the same noisy inflation target, so that expectations are coordinated, whereas, in Scenario 3, each household has its own perceived inflation target, and expectations can be heterogeneous. Admittedly, the CB perfectly knows its own inflation target and, in case of complete credibility, the announced target should be perfectly perceived. However, in Scenario 2, the prevalence of a noisy target can be interpreted as a proxy for the information the CB communicates as a whole (including its inflation forecasts, for example) and that information is mostly noisy (Dale et al. (2011)). Scenario 2 is, therefore, designed to investigate the consequences of expectations coordination on a wrong public signal. We believe such a case is particularly interesting because a wave of contributions (initiated by Morris & Shin (2002)) has highlighted the fact that agents tend to exclusively rely on public information, which can become costly if that information is imperfect. That could also be true 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 also to divergent interpretations of the CB communication. CB announcements can also be differently perceived or differently broadcast by media (see the contributions surveyed in Blinder et al. (2008)). In that case, ξ_i denotes a kind of private noise, and individuals hold different expectations.

Scenarii 4 and 5 are designed to investigate the lack of credibility of the CB communication. In those cases, households perfectly perceive the inflation target but rely only partially on it. They also take into account past observations to anticipate future inflation rates (values of χ in Scenario 4 are given in Section 3). This modelling of partial credibility is very close to that in Brazier et al. (2008) and De Grauwe (2011). Furthermore, it is consistent with the findings of Roos & Schmidt (2012), who show that backward-looking behaviour is a decisive factor in expectations formation by non-economist people, such as households. Scenario 5 is the nested case of no credibility, where individuals form completely adaptive expectations.

We now describe how markets work, and determine aggregate dynamics in the

signals.

model.

2.5 Market interactions

As stated above, we do not assume market clearing, focusing on disequilibrium dynamics, as well as on equilibria that may result from the learning processes of the agents. Consequently, markets confront individual supplies and demands according to rationing mechanisms. We adopt mechanisms that reinforce the similarity of market structures with the ones of the NK framework.

Labour market The firm's strategy is the aggregate demand of labour H_t^d, and aggregate supply is simply given by:

$$H_t^s = \sum_{i=1}^{n} h_{i,t}^s = n \tag{18}$$

Both are matched according to a process which is designed to be consistent with the assumption that the firm aims at minimizing its production costs. The firm sorts households by increasing desired wages, and hires the less demanding ones first. The aggregate hired labour is then set as:

$$H_t = \min(H_t^d, n) \equiv \sum_{i=1}^{n} h_{i,t} \tag{19}$$

Unemployment rate is computed as $u_t = \frac{n-H_t}{n}$, and the real wage rate is given *ex post* by $\omega \equiv \frac{W_t}{P_t} = \frac{(1-\alpha)}{(1+\mu)} H_t^{-\alpha}$, where W_t is the aggregate wage defined in Section 2.2. Variable ω is decreasing in function of H and reaches a minimum equal to $\frac{(1-\alpha)}{(1+\mu)} n^{-\alpha}$, when full employment is reached.

Good market Aggregate labour (19) yields aggregate good supply Y_t^s through production function (9), and aggregate good demand is given by (see Equation (2)):

$$C_t^d \equiv \sum_{i=1}^{n} c_{i,t}^d \tag{20}$$

Both are matched according to an efficient rationing mechanism: households are ranked by decreasing good demand, so that the firm meets the highest demand first. We choose that rationing scheme in order to be in conformity with the assumption of utility maximisation assumed in the NK model. If a household is rationed, it buys bonds with its remaining cash on hand. Inflation π_t is computed as $\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}}$. A special case obtains when full-employment is reached and the firm can sell all its production. In that case, its rate of profit reaches a maximum level equal to $\frac{(\alpha+\mu)}{(1+\mu)} n^{1-\alpha}$.

As the model is now fully specified, we proceed to discuss the monetary policy channels in the model.

2.6 Discussion

In the NK framework, dynamics arise in the following way: price stickiness creates a discrepancy between current production and its natural level, which prevails in a fully flexible price environment. In the long run, the natural product is constant, reaching a steady state level. Two kinds of shock are introduced in this framework. Real shocks make the natural product fluctuate around the steady state level, and impact the inflation rate through an effect on the output gap (i.e. the gap between the output and its steady state value). Cost-push shocks directly affect the Phillips curve and, hence, inflation dynamics. Our model works in a rather different way.

First we assume a deterministic natural production level, with $A_t = 1$, $\forall t$ (the long run value of the technology defined by Woodford (2003, p. 225)). Consequently, we assume a constant natural real interest rate r_t^n, equal to zero. In NK models, r_t^n is a function of agents' time preference, and of real shocks, which modify the natural production level. In our model, however, there is no explicit time preference, because agents do not solve intertemporal optimization programmes. We also assume that the natural level of unemployment u^* is zero, so that the resulting natural level of production equals $n^{1-\alpha}$. That value represents the potential production level, i.e. the level prevailing if all the labour supply is employed, which is the situation the CB is targeting (see Equation (16)).

Two phenomena are likely to move inflation and unemployment away from the values aimed at by the CB. On the one hand, the departure from the rational expectations benchmark has been shown to endogenously result in macroeconomic volatility, and to create business cycles (see, for example, De Grauwe (2011)). On the other hand, households' learning creates volatility in the model, through the random exploration of the space of households' strategies, which is captured by shocks σ_{mutW} and σ_{mutK}. Those shocks cannot be directly translated either in terms of demand/supply shocks, as they are in standard Keynesian macroeconomic models, or in terms of real/cost-push shocks, as in NK models.

However, we can assimilate the effects of shocks σ_{mutW} to those of cost-push shocks in the NK model, because they directly create volatility in the inflation rate through the wage/price spiral (*i.e.* through second-round effects, see Heuristic (1)). Inflation can be driven only by inflation expectations (first term of Equation (23) below), and does not convey information about the good market (and labor market) any more (second term of Equation (23))[10]. These shocks are therefore likely to introduce a trade-off between the two objectives of the CB.

As for shocks σ_{mutK}, they introduce volatility in the way interest rates affect the aggregate demand (see Heuristic (6)). That kind of volatility has been emphasized in the literature as model uncertainty or transmission channel uncertainty (see, for instance, Söderström (2002)). We also note that shocks σ_{mutK} can be interpreted as demand shocks in NK frameworks, in which the demand side is reduced to the CB's intended output gap, up to a control error (see, for example Walsh (2007)).

Consequently, the effects of monetary policy depend upon the relative magnitudes of the shocks σ_{mutK} and σ_{mutW}, as it will be clear from Section 4 below.

In order to illustrate that point, let us write the inflation rate as (see Equation (12)):

$$\pi_t \equiv \frac{\Delta P}{P_{t-1}} = \frac{\Delta \Psi}{\Psi_{t-1}} - (1-\alpha)\frac{\Delta H}{H_{t-1}} \tag{21}$$

where ΔX stands for the variation of variable X between periods $t-1$ and t. With equation (10), we can write $\Delta\Psi \equiv \sum_{i=1}^{n} w_{i,t-1}\Delta h_i + h_{i,t-1}\Delta w_i$, and through equation (1), we have:

$$\Delta w_i = \mathbb{1}_{(\pi^e_{i,t+1}>0)}(\gamma^w_{i,t}\pi^e_{i,t+1}w_{i,t-1}) \tag{22}$$

which implies $\Delta w_i \geq 0,\ \forall i,t$. By rearranging terms in (21) and using $\Delta H \equiv \sum_{i=1}^{n}\Delta h_i$, the inflation rate in the model is given by:

$$\pi_t = \frac{\sum_{i=1}^{n}\Delta w_i h_{i,t-1}}{\Psi_{t-1}} + \sum_{i=1}^{n}\frac{\Delta h_i}{H_{t-1}}\left(\frac{w_{i,t-1}}{W_{t-1}} + \alpha - 1\right) \tag{23}$$

Inflation is driven by two components. First, inflation is positively related to nominal wages growth rate (Δw_i), which positively depends on both inflation expectations $\pi^e_{i,t+1}$ and indexation strategies $\gamma^w_{i,t}$ (see Equation (22)). Coefficients γ^w_i stand for the strength of second-round effects, through which the expected inflation

[10] Interestingly, Clarida et al. (1999, p. 1667)) suggest such an interpretation of cost-push shocks, which are introduced in the NK Phillips curve to allow for a trade-off between inflation and output gap.

feeds back into the actual inflation through wages. Second, inflation increases in function of the rise in employment (Δh_i). In order to understand this point more clearly, let us take the case of an increase in labour demand from period $t-1$ to period t. As the firm sorts households in ascending order regarding their desired wages, the households that become employed in period t, were necessarily demanding, in period $t-1$, a wage higher than the average. As a consequence, for those households, we have $\frac{w_{i,t-1}}{W_{t-1}} \geq 1 > 1-\alpha$, and the second term of Equation (23) is positive. The reverse is true if labour demand decreases and, consequently, the inflation rate is positively related to variations in employment.

Consequently, Equation (23) is the ABM counterpart of the expectation-augmented Phillips curve in the NK framework.

A specific case prevails if full-employment is reached: we have $h_{i,t-1} = h_{i,t} = 1 \Rightarrow \Delta h_i = 0$, $\forall i$, $H_{t-1} = H_t = n \Rightarrow \Delta H = 0$ and $\Psi_{t-1} = \sum_{i=1}^{n} w_{i,t-1}$. By combining those elements with Equation (22), we can write the inflation rate as:

$$\pi_t = \frac{\sum_{i=1}^{n} \gamma_{i,t}^{w} \pi_{i,t+1}^{e} w_{i,t-1}}{\Psi_{t-1}} \tag{24}$$

In that case, it is in the CB's interest that coefficients $\gamma_{i,t}^{w}$ remain on average equal to one (i.e. $\sum_{i}^{n} \gamma_{i,t}^{w} = n$), and households' inflation expectations remain equal to the target (i.e. $\pi_{i,t+1}^{e} = \pi^T$, $\forall i$), which implies $\pi_t = \pi^T$. If σ_{mutW} is high, indexation strategies can depart strongly from the previous average ones, thereby introducing volatility in nominal wages growth and, hence, in the inflation rate.

In a comparable way, variability induced by σ_{mutK} affects the consumption channel of monetary policy. It should be recalled that monetary policy affects demand through the nominal interest rate that, together with agents' inflation expectations, determines the real interest rate, which is relevant for consumption decisions (see Equation (6)). This transmission channel is in the spirit of the IS relation in NK models derived from the Euler relation. Formally, for each household i, the expected real interest rate $r_{i,t+1}^{e} \equiv i_t - \pi_{i,t+1}^{e}$ between period t and $t+1$ has a immediate effect on its demand (see Equation (6)):

$$\frac{\partial c_{i,t}^{d}}{\partial r_{i,t+1}^{e}} = \frac{\partial k_{i,t}}{\partial r_{i,t+1}^{e}} \times \tilde{y}_{i,t} = -\gamma_{i,t}^{k} \tilde{y}_{i,t} \tag{25}$$

and a one-period-ahead effect:

$$\frac{\partial c^d_{i,t+1}}{\partial r^e_{i,t+1}} = \frac{\partial k_{i,t+1}}{\partial r^e_{i,t+1}} \times \tilde{y}_{i,t+1} + k_{i,t+1} \times \frac{\partial \tilde{y}_{i,t+1}}{\partial r^e_{i,t+1}} \tag{26}$$

$$= -\gamma^k_{i,t}\tilde{y}_{i,t+1} + k_{i,t+1}(1-\rho)\frac{b_{i,t}}{P_t} \tag{27}$$

If household i adopts a strategy with $\gamma^k_{i,t} > 0$, a rise in the expected real interest rate yields to a decrease in its demand (see Equation (25) and the first term of (26)): the substitution effect dominates. If household i adopts a $\gamma^k_{i,t} < 0$ strategy, the consumption share rises if the real interest rate is above its natural level, and the income effect dominates. Coefficients $\gamma^k_{i,t}$ have to be mostly positive for the CB to influence demand in such a way that an increase in the nominal interest rate achieves a slowdown in demand (which corresponds to the usual consumption channel of monetary policy; see, for example, Walsh (2003, p. 248)). The second term in (26) is positive if $b_{i,t} \geq 0$, and negative otherwise, and represents the wealth effect of a change in the real interest rate. High positive values of coefficients γ^k imply that demand is more sensitive to changes in the interest rate, thereby improving the efficiency of the consumption channel. Furthermore, if households' inflation expectations are coordinated, i.e. if $\pi^e_{i,t+1} = \pi^e_{t+1}$, $\forall i$, changes in the nominal interest rate produce changes in the real expected interest rates in the same proportion among households, and monetary policy more efficiently controls demand. High values of the shocks σ_{mutK} induce high variability in the way monetary policy influences aggregate demand. Those shocks may be interpreted as reflecting different degrees of uncertainty surrounding the aggregate demand transmission channel.

In short, the monetary authorities try to stabilize inflation and employment facing i) a global uncertain context due to the heuristic forms of behaviour of agents, in which ii) variability in the price level (through second-round effects) can be more or less strong and iii) the real transmission channel of monetary policy may be more or less stable.

3 Simulation protocol

In our model, we first analyse the impact of monetary policy in relation with the way expectations are formed, and how those expectations interplay with the learning environment, and then focus on the resulting macroeconomic performances. We choose to set all the structural parameters of the model at the same level for each scenario to ensure their comparability. Moreover, we adopt for these parameters values that are inline with the NK literature. We set $\alpha = 0.25$ (Woodford (2003)) and $\mu = 0.1$ (Rotemberg & Woodford (1998), Woodford (2003)) and $\pi^T = 0.02$, as that value corresponds to the target of most CBs in developed countries, and $\epsilon = 0.01$, $\bar{k} = 1.5$, $\underline{k} = 0.5$[11]. We focus on the impact of the learning and monetary policy parameters. We define three levels of learning[12]: a slow one $(P_{imit}, P_{mut}) = (0.05, 0.01)$, and two more active ones $(P_{imit}, P_{mut}) = (0.1, 0.05)$ and $(P_{imit}, P_{mut}) = (0.15, 0.1)$. We set $(\sigma_{mutK}, \sigma_{mutW}) \in [0.05, 0.4]^2$, $\phi_\pi \in [0, 2]$, $\phi_u \in [0, 1]$, $\sigma_\xi \in [0.001, 0.05]$, $\chi \in \{0.1, 0.2, ..., 0.9\}$ and $\rho \in \{0, 0.45, 0.9\}$[13].

We use a *design of experiments* to sample that space of parameters[14]. Large sampling methods such as Monte Carlo simulations come at a high computational cost, if there are numerous parameters with large experimental domains. We have to run a very high number of simulations to obtain a representative sample of all parameter configurations. Design of experiments allows us to minimize the sample size under constraint of representativeness, thereby providing a design of all parameters (or factors) configurations. Certain properties of the design are particularly useful: space-filling properties, i.e. the design has to correctly cover the whole space of parameters; the non-collapsing criterion, which ensures that each point is uniquely tested; non-correlation between configurations of parameters, which avoids multi-collinearity issues in result analysis. We use the design proposed by Cioppa (2002), which offers an interesting combination of those three properties. We then study 17 parameter settings (or experiments, see Appendix A). We have $n = 500$ households and $T = 800$ periods[15]. As the model is not deterministic, each experiment is re-

[11]Those values are chosen according to the results of extensive sensitivity analyses performed on the model (available on request). As the model's dynamics have been found to be disturbed only by extreme values of those parameters – precisely $\epsilon > 0.05$, $\bar{k} > 2$, $\underline{k} < 0.2$, we rule out those values.

[12]These values are standard in the literature on learning through genetic algorithms, see, for instance, Arifovic (1995), Arifovic et al. (2012) or Yıldızoğlu et al. (2012).

[13]The weight of the $t - n^{th}$ period in moving averages of the form (7) is equal to ρ^n. To that respect, $\rho \in \{0, 0.45, 0.9\}$ corresponds to three magnitudes of memory in behaviour: a memoryless one, a few periods backward-looking one and many periods backward-looking one ($0.9^{45} \simeq 0.45^6$).

[14]See, for example, Goupy & Creighton (2007) and Salle & Yıldızoğlu (2012) for a pedagogical statement. That method is widely used in computer simulations in areas such as industry, chemistry, computer science, biology, etc. To the best of our knowledge, Oeffner (2008) and Yıldızoğlu et al. (2012) are the only applications concerning an economic ABM.

[15]That 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 that horizon is enough to stabilize aggregate welfare, and to significantly allow the learning process to take place.

peated 20 times in order to take into account the randomness of initialization and the learning process. Each variable is saved at every 50 period. The first 100 periods have been discarded, in order to rule out the effects of initialization on the analysis. We then have $5,100$ data points for each response variable in each scenario. The following section compares the resulting outcomes in the five scenarii.

4 Results

According to the literature surveyed so far, two dimensions play a major role for IT performances: the precision and credibility of the target. We aim at assessing how those two factors affect IT performances in our learning economy. In that respect, we first analyse how the model works when the target is perfectly clear and credible (Scenario 1), which allows us to see how learning operates and interplays with the working of the economy under a perfectly clear and credible IT regime. We then assess how noisy communication or partial credibility can cause deviations from that benchmark.

In order to perform that analysis, we implement, for each scenario, a quadratic regression of the (squared) unemployment rate and inflation gap 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 (see Table 5 in Appendix B). Quadratic regression gives more detailed insights into the effects of those coefficients than linear regression does, all the more so as our model is non-linear by nature. We consider squared variables, in order to express CB's objectives like in standard loss functions (see, for example, Svensson (1999)). We also apply the welfare criterion of Lucas (2003), a method for comparing policy outcomes that is expressed in comprehensive units, and is built up from individual preferences (see Table 3).

4.1 The benchmark case: behavioural learning and IT

In our model, variability arises from two sources: one is structural, resulting from the learning process of agents; the other is due to the way inflation expectations are formed. In Scenario 1, inflation expectations are well anchored to the target, so that macroeconomic variability only comes from agents' learning. Accordingly, that scenario clearly exhibits the lowest volatility as far as average agents' behaviour,

					Scenario
	1	2	3	4	5
$\pi_t - \pi^T$	-0.0026	0.0029	-0.0015	0.0057	0.0926
	(0.012)	(0.0357)	(0.0184)	(0.0624)	(0.1958)
u_t	0.0874	0.1715	0.1281	0.1795	0.228
	(0.2068)	(0.3037)	(0.2595)	(0.2968)	(0.3239)
$mean(\gamma^w_{i,t})$	0.9416	1.033	1.0165	0.995	1.0875
	(0.40)	(0.36)	(0.414)	(0.4661)	(0.5825)
$mean(\gamma^k_{i,t})$	0.6585	0.557	0.6502	0.6246	0.5733
	(0.1998)	(0.2832)	(0.211)	(0.1964)	(0.2668)
$var(\gamma^w_{i,t})$	0.053	0.06	0.0596	0.059	0.0552
	(0.0495)	(0.0477)	(0.0482)	(0.0469)	(0.0432)
$var(\gamma^k_{i,t})$	0.0558	0.0613	0.0607	0.0611	0.0586
	(0.0508)	(0.05)	(0.0487)	(0.0489)	(0.0489)
Pearson correlation tests between u^2 and $(\pi - \pi^T)^2$					
correlation	0.153***	-0.056**	0.007	-0.09***	-0.211***
(p-value)	(<2.2e-16)	(0.001)	(0.667)	(1e-07)	(<2.2e-16)

Table 2: Mean and standard deviation in brackets of agents' behaviour and macroeconomic performances over the whole set of simulations (340 runs, data saved every 50 periods, 5,100 data points per scenario).

heterogeneity and macroeconomic performances are concerned[16]. Moreover, average levels of unemployment and inflation are the lowest over the 5 scenarii. That comes from the particular strategies that agents adopt in Scenario 1. First, the mean indexation coefficient is significantly lower than unity. As $\pi^e_{i,t+1} = \pi^T$, $\forall i, t$, nominal wages grow at a rate lower than the target, and so do prices (see Equations (23) and (24))[17]. Second, average substitution coefficients reach the highest level and remain positive, which favours the control of demand by the CB (see Sub-section 2.6). Unemployment is on average equal to 9%, which can appear high, but that variable displays rather strong volatility[18].

We now compare Scenario 1 with Scenario 5, in order to assess the benefits from a perfectly clear and credible target. Figure 1 illustrates the dynamics of the model in Scenario 1 in comparison to those in Scenario 5, in the absence of a credible target (Scenario 5). Although the emerging behaviour and macroeconomic

[16]For example, t-tests at 5% lead to strongly rejecting the null hypothesis that the variability of γ^k and γ^w among households is equal across the 5 scenarii, against the alternative that it is smaller in the benchmark scenario.

[17]t-tests at 5% lead to rejecting the null hypothesis $\pi_t - \pi^T = 0$, against the alternative $\pi_t - \pi^T < 0$ ($t - stat = -9.0953$, $p - value < 2e - 16$), and to rejecting the null hypothesis mean$(\gamma^w_{i,t}) = 1$, against the alternative mean$(\gamma^w_{i,t}) < 1$ ($t - stat = -7.415$, $p - value = 8.23e - 14$).

[18]Full-employment wage rate level equals 0.1442 under our calibration. Average real wage in Scenario 1 reaches a higher level on average (0.1514 with a standard deviation of 0.0223). Variability in indexation strategies, leading to imperfect adjustments of the nominal wage W can explain why unemployment may arise in Scenario 1, despite the fact that inflation expectations are fully anchored at the target.

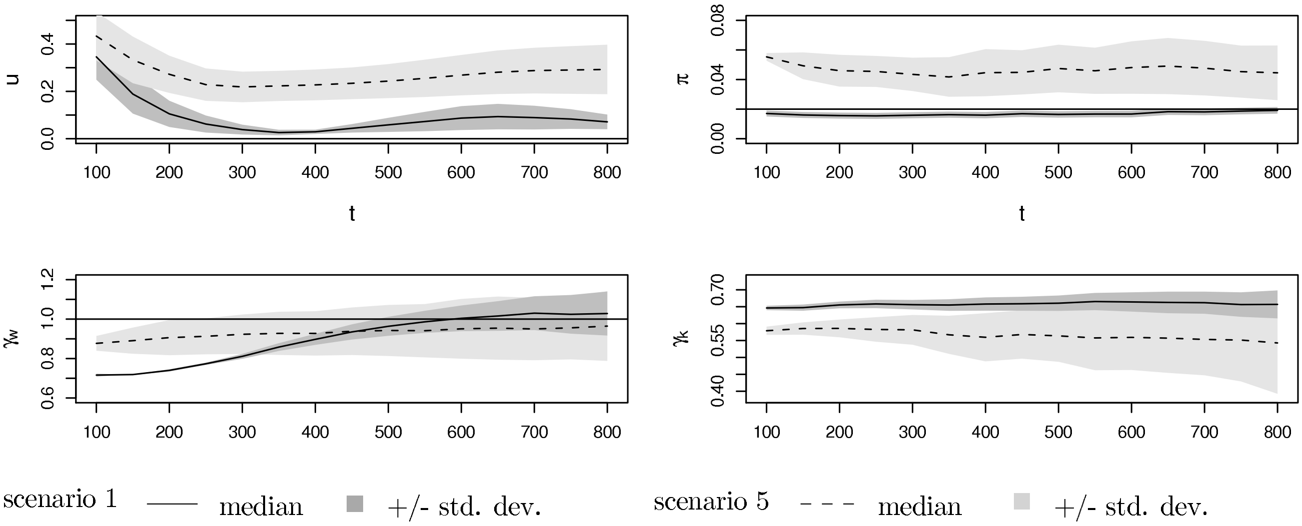

Figure 1: Dynamics in Scenarii 1 and 5 in Experiment 8 overall 20 runs.

Experiment 8 has been chosen to illustrate the model's dynamics because its parameters values are close to the average of their variation domains (see Table 4 in Appendix A).

performances strongly differ between the two scenarii, the more salient difference concerns variability: the model is much more stable under Scenario 1.

The results of the econometric analysis, reported in Table 5 in Appendix B provide further insights about those rather good performances in Scenario 1. Shocks σ_{mutW} have a positive effect on the inflation gap, but the estimated coefficient is the weakest one over the 5 scenarii. By contrast, those shocks do particularly contribute to moving inflation far from the target in the absence of a credible target (Scenario 5). Under Scenario 1, shocks σ_{mutK} do not influence CB's performances, whereas they significantly affect the unemployment rate in Scenario 5.

On the whole, learning is associated with a better convergence towards both CB's targets and increasing welfare in Scenario 1 (see Table 5 in in Appendix B) , whereas its influence is more contrasted in Scenario 5 (see Figure 3, in Appendix B). That result is in line with previous ones, which have established that the announcement of policy objectives helps the CB to better stabilize the economy when private agents are engaged in a perpetual learning process (see, notably, Orphanides & Williams (2005, 2007), De Grauwe (2011)).

Finally, we compare the role of monetary policy across the two scenarii. As displayed in Figure 2, the role played by coefficients ϕ_π and ϕ_u of the monetary policy rule in Scenarii 1 and 5 is very different. In order to stabilize the economy, the CB's reaction is less constrained in Scenario 1: as soon as $\phi_\pi > 0.8$ and $\phi_u > 0.36$, the inflation gap and the unemployment rate start to decrease. By contrast, with no

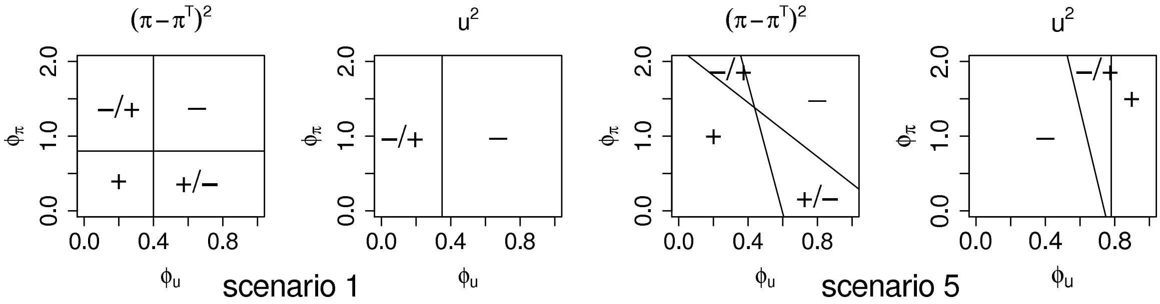

Figure 2: Sign of the estimated derivatives (based on 0.1-significant OLS estimated coefficients, see Table 5) of $(\pi - \pi^T)^2$ and u^2 with respect to ϕ_π and ϕ_u.

We make explicit the pairs of coefficients (ϕ_π, ϕ_u) which have a negative or a positive effect on the CB's objectives (taken as quadratic deviations from the targets). For values of the coefficients that have the same impact on *both* the inflation gap and unemployment rate (either negative, denoted by "-" or positive, denoted by "+"), the CB does not face any trade-off between its objectives, and the conduct of monetary policy is made easier. If some pairs of coefficients have a negative impact on one objective, but a positive one on the other ("-/+" indicates that the derivative is negative with respect to ϕ_π and positive with respect to ϕ_u, and "+/-" the reverse), the CB does face a trade-off between the two objectives. In that case, it stabilizes one objective at the expense of the other, making the achievement of both objectives more challenging.

credible target, only a hawkish reaction to inflation, combined with a strong reaction to unemployment can decrease the inflation gap. Intuitively, we can conceive that such a strong reaction is necessary to offset unstable deflationary or inflationary patterns, which are created by purely adaptive expectations.

This result in Scenario 5 is in line with previous statements in the literature that address settings in which private agents' forecasts are based on learning rules, notably adaptive rules (see, for instance, Howitt (1992)). As in those papers, we also conclude that the Taylor principle has to prevail in order to stabilise inflation dynamics. By considering two objectives in the monetary policy rule, we are able to further show that such a policy comes at the expense of the stabilisation of the level of activity. The correlation tests reported in Table 2 confirm this analysis. There is no trade-off between the two objectives in Scenario 1: they are significantly and positively correlated. On the contrary, a negative correlation between the two objectives in Scenario 5 emerges (see Table 2).

Interestingly, in Scenario 1, hawkish reactions appear to better stabilize the economy, but the so-called Taylor principle (i.e. the condition $\phi_\pi > 1$) does not emerge as a critical threshold. That result can be related to two strands of literature.

On the one hand, monetary policy rules that are designed to be robust in a context of uncertainty, especially uncertainty concerning the true model of the economy and/or the transmission channels of monetary policy, have been identified as rules that respond aggressively to inflation and output gap (see, for example, Tetlow & von zur Muehlen (2001)). In our model, the CB is clearly confronted with such an uncertainty.

On the other hand, we can compare our results to those obtained in NK models, as Scenario 1 is the closest to that framework. In NK models, the Taylor principle has been emphasized as a major requirement. Two issues are critical. First, under rational expectations, the baseline NK model is determinate, i.e. converges to a unique stationary equilibrium path designed to be consistent with CB objectives, as soon as ϕ_π is sufficiently high, typically higher than 1 (see Woodford (2003)): the so-called Taylor principle. Second, Bullard & Mitra (2002) show that the Taylor principle is a necessary and sufficient condition for that unique equilibrium to be learnable under least squares learning, i.e. for agents' beliefs to eventually match the true driving process of the economy (the so-called "law of motion"). In the ABM, the Taylor principle does not appear to be discriminant, suggesting that the CB can stabilize inflation and unemployment with weaker values of that coefficient. That result is in line with several contributions, which put the importance of the Taylor principle in a learning environment into perspective. In the linearized version of the NK model, Arifovic et al. (2012) assess whether the system can converge to the rational expectations equilibrium, if learning operates through a social learning mechanism modelled with a genetic algorithm. Those authors find that that is mostly the case, even when the Taylor principle does not hold. In an ABM, in which 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 stable solution. In numerical experiments using the NK baseline model, Lipinska & Yates (2010) conclude that the performance of the economy is almost invariant in terms of the type of monetary policy rule conducted, when the signal of the CB about the inflation target is very precise and credible, as is the case in our Scenario 1.

To conclude our comparison, we obtain the following proposition:

Proposition 1 *When inflation expectations are well-anchored to the target, the conduct of monetary policy is made easier, and the CB does not face any trade-off between inflation and unemployment. In particular, the meeting of the so-called Taylor principle (i.e. the condition $\phi_\pi > 1$) does not appear as a critical threshold, although hawkish reactions do better stabilize the economy.*

4.2 What is the impact of imperfect communication?

The case of imperfect communication occurs in Scenarii 2 and 3. In Scenario 2, we assume a single draw of the perceived inflation target, with some noise σ_ξ around the announced target, and households share the same inflation expectation. Inflation expectations are thus homogeneous, but the more noise there is, the further they can be from the target. In Scenario 3, households perception errors can be different; their perception of the target is distributed around the target, with some noise $\frac{\sigma_\xi}{n}$: consequently, *average* inflation expectation is equal to the target, but inflation expectations are heterogeneous. In that case, the more noise there is, the more scattered expectations are around the target and, hence, the more heterogeneous they are.

Thus, imperfect communication introduces volatility into the model's dynamics. That is clear from the outcomes of the simulations: inflation is on average closer to the target in Scenario 3 than it is in Scenario 1, probably because indexation coefficients are closer to 1. However, inflation in Scenario 3 exhibits greater volatility. Furthermore, unemployment rate is both higher and more volatile. In Scenario 2, macroeconomic outcomes are worse than in Scenario 1, both in terms of level and volatility. They are also worse than in Scenario 3[19].

The econometric analysis provides further elements of comparison. When the target is imperfectly communicated, the learning environment globally favours convergence towards the macroeconomic objectives, but that role is less salient than in Scenario 1. Shocks σ_{mutW} affect both inflation and unemployment in Scenario 2, and inflation in Scenario 3, in each case in a stronger way than in Scenario 1. Those effects are especially strong in Scenario 2, in line with the worst macroeconomic performances we observe. However, shocks σ_{mutK} do not impact the CB's objectives, either in Scenario 2 or in Scenario 3.

In what concerns monetary policy, its action on the two objectives is strongly disturbed. In Scenario 2, only a moderate reaction to inflation ($\phi_\pi < 1.5$) achieves a negative effect on inflation, and monetary policy does not affect unemployment. It should be remarked that average γ^k strategies are particularly low in that scenario. As those strategies define the responsiveness of demand to changes in interest rate

[19]t-tests performed on both samples lead to rejecting the null hypotheses of equal inflation gap and unemployment rate between Scenarii 2 and 3, against the alternative ones of a greater inflation gap ($t-stat = 7.9, p-value = 1e-15$) and a higher unemployment rate ($t-stat = 8.6, p-value < 2.2e-16$) in Scenario 2.

(see Equations (25) and (26)), the consumption channel of monetary policy is less efficient in Scenario 2, than it is in Scenario 1. Interestingly, once again, the Taylor principle does not emerge as a desirable property of the Taylor rule. In a simulated version of the NK model, Fukac (2008) finds a similar result: if the CB and the private agents hold divergent inflation expectations, that creates a mismatch between the real interest rate expected by agents, which determines the evolution in aggregate 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 that mismatch on macroeconomic volatility. Monetary policy exerts a stronger influence on employment in Scenario 3: as soon as $\phi_u > 0.5$, the unemployment rate decreases when the CB reacts more strongly. Nevertheless, that drop comes at the expense of inflation stabilisation. Finally, noise in inflation expectations probably adds to variability in learning, and thus exacerbates heterogeneity in agents' behaviour, thereby explaining the worse performances in Scenarii 2 and 3.

Those results can be related to the debate on the potentially negative effect of transparency in the conduct of monetary policy (see Baeriswyl & Cornand (2011) for a review). Contributions such as Morris & Shin (2002) or Ueda (2010) argue that private agents are likely to focus too much on public information to form their own expectations. In the case of monetary policy, that means that agents may completely rely on the CB's announcements to expect inflation. Therefore, if the disclosed information is noisy, there is a risk that the effect of that public noise becomes amplified and macroeconomic performances worsen. In particular, i) if public information is very imprecise in comparison to agents' private information (Woodford (2005) and Svensson (2007), *inter alia*), 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 ξ_i/n in Scenario 3 as the noise in private information, our result confirms the above statements. Macroeconomic instability is worse when the announced target is highly imprecise regarding the true inflation objective than it is when individuals hold heterogeneous inflation expectations, but which are *on average* closer to the target. In Scenario 2, agents completely rely on the CB information ($\chi = 1$) and are, therefore, not aware that that information can actually be imperfect.

As a conclusion to this sub-section, we highlight the following proposition:

Proposition 2 *Imperfect communication may be associated with two configurations regarding inflation expectations:*

1. *Heterogeneity in inflation expectations, i.e. a lack of coordination between individuals.*
2. *The misanchoring of inflation expectations (in the sense of coordination on a point far from the CB's objective), i.e. a lack of coordination between the CB and individuals.*

Those two situations create more heterogeneous agents behaviour, leading to macroeconomic instability and restricting the extent to which monetary policy manages to stabilize both inflation and unemployment. Nevertheless, it appears that coordination of expectations on a very noisy target results in the worst outcomes.

We now consider the question of credibility of the inflation target.

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

We now compare the outcomes in Scenario 4 (partial credibility of the announced inflation target) and in Scenario 5 (no credibility at all) with the benchmark case. It is clear that the less credible the inflation target, the further macroeconomic outcomes are from the CB's objectives, both in terms of level and volatility. As previously mentioned, Scenario 5 clearly exhibits the worst macroeconomic figures.

Surprisingly, in Scenario 4, heterogeneity of behaviour is higher than in Scenario 5, both as regards the substitution strategies and the indexation coefficients. However, macroeconomic outcomes are clearly better. That is especially the case as far as the inflation rate is concerned. This indicates that the anchoring of inflation expectations to the target is the primary determinant of macroeconomic stability, a result which stems from the way expectations are formed without a perfectly credible inflation target in the model. As agents also rely on past inflation trends, inflation expectations are partly driven endogenously by past inflation and, therefore, can become unanchored. In the model, as expectations patterns are exogenously 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.

However, the results of the regression show that the conduct of monetary policy becomes more complicated when the inflation target is partially credible and, much more so even, in the absence of credibility. Shocks σ_{mutK} strongly affects inflation dynamics: endogenous expectations strengthen the impact of that variability on inflation. Therefore, the CB is faced with a strong trade-off, as confirmed in Table 2, in which a negative and significant correlation between the two objectives is displayed in Scenario 4. That correlation becomes even higher in case of no credibility at all (Scenario 5), as previously stressed. We conclude that partially endogenous expectations disturb the stabilizing power of monetary policy, which enables us to establish the following proposition:

Proposition 3 *Credibility, which we measure as the degree of anchoring 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 endogenous expectations, which highly disturb the ability of the CB to react to learning shocks affecting the economy, thereby creating a trade-off between the two objectives.*

The crucial role played by credibility has already been pointed out in many contributions. De Grauwe (2011) notably shows how a CB can make the trade-off between its two objectives easier to face by enhancing the credibility of its explicit inflation target.

As the number of agents in our model is high (500), we can interpret Scenario 4 as a situation in which a proportion of agents χ uses the target to expect inflation, and a proportion $1-\chi$ uses the adaptive rule. We could then discuss our results regarding the heterogeneous agent literature, in which different forecasting rules compete on the basis of their relative costs and performances[20]. A major difference, yet, is that proportions of rules are exogenously fixed in our setting, while the main driving force in that literature is the endogenous switches between rules. Consequently, in our model, inflation cannot be driven back close to the target by an endogenous switch of expectations to the target. However, as Anufriev et al. (2008) and Branch & McGough (2010), we show the destabilizing effect of a fraction of agents using an adaptive rule, and we are able to emphasize the limiting power of monetary policy to offset those destabilizing effects.

[20] See, for instance, Brock & Hommes (1997), Anufriev et al. (2008), Branch & McGough (2010) or De Grauwe (2011).

benchmark	scenario 2	scenario 3	scenario 4	scenario 5
scenario 1	0.0416	0.0211	0.0576	0.2252

Table 3: Welfare losses associated to each scenario in comparison to the benchmark one.

According to Lucas (2003), the welfare gain of a change in policy from A to B is given by λ such as $u((1+\lambda)c_A) = u(c_B)$, where c_A and c_B stand for the good consumption of the representative agent under policy A and B and $u(c_A) < u(c_B)$. λ is expressed in units of percentage of all consumption goods. Conversely, we interpret the welfare losses of partial credibility as λ, where λ satisfies $u(c_1) = u((1-\lambda)c_4)$ and c_1 and c_4 are the median consumption units at the end of the runs (i.e. at $T = 800$) in Scenarii 1 and 4. In Scenario 4, the lack of credibility leads to a decrease of 5.76% in the median good consumption.

Finally, Boxplots 3 in Appendix B and the welfare losses reported in Table 3 confirm the above findings. We show how aggregate welfare (computed as the sum of individual utilities) evolves through time under each scenario. Clearly, the first scenario outperforms the other four, by allowing welfare to strongly increase and to stabilize at a high level, which provides an obvious sign of learning in our model. The second, third and fourth scenarii also exhibit an increasing trend in welfare. However, more variability remains at the end of the simulations, especially in the second and fourth ones. The last scenario is clearly the worst, in line with the higher unemployment rates we observe. On the other hand, welfare losses represent the percentage of consumption individuals lose in comparison to the benchmark case, in which expectations are well-anchored to the target (Scenario 1). Those findings are consistent with the above analysis.

5 Conclusion

Two issues play a primary role in the performances of an IT regime: the degree of imprecision and the degree of credibility of the inflation target. Previous contributions have highlighted how noise in public and private information can affect the conduct of monetary policy and deteriorate macroeconomic performance. Those results have been established in various analytical models, notably using the NK framework, which has become the workhorse for macroeconomic analysis in the field. The need for credibility has also been shown in learning models in which, however, the core structure remains close to that of the main framework. This paper is an attempt to revisit those issues using an ABM. This perspective allows us to consider heterogeneous and interacting agents which are engaged in a learning process, and, in consequence, to emphasize how crucial the interplay of learning mechanism and IT features is for IT performances. This is very much in line with the description of IT as "a framework designed for a world of learning" (King (2005)). Thanks to our simple model, we are able to assess how imperfect information and the lack of credibility of the inflation target can disturb the conduct of monetary policy, and worsen the resulting macroeconomic performances. Our main findings are as follows:

- A perfectly clear and credible inflation target makes the conduct of monetary policy easier. In that context, the Taylor principle does not emerge as a critical condition for macroeconomic stabilization, although hawkish reactions do better achieve monetary policy objectives.
- 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 the two cases, such noise restricts the influence of the Taylor rule and introduces a trade-off between the objectives. The situation clearly worsens when agents rely totally on highly noisy public information, which obviously contributes to the recent debate on the need for transparency, set against the welfare costs of imperfect public information.
- If the inflation target is not completely credible, private expectations become endogenously driven by past inflation, which strongly disturbs the ability of the CB to react to shocks, and creates a steep trade-off between the two objectives. We therefore highlight the primary role of credibility in achieving both full-employment and inflation stability, very much in line with the findings of recent contributions in macroeconomic learning models.

These promising results demonstrate the interest of using the agent-based framework to investigate macroeconomic dynamics under learning and bounded rationality, and call for further analysis in such a context. We are notably working on a version of our model, in which inflation expectations are made endogenous, according to various expectations schemes, in order to assess how the CB communication can influence those private expectations.

As an another interesting extension, we could also enrich the model, by introducing other transmission channels of monetary policy, which could turn out to be valuable when the zero lower bound of the interest rate is reached. In particular, considering an open economy could be an interesting topic for further research, as exchange rate dynamics have been widely discussed in the literature on learning through genetic algorithms (see, for instance, Arifovic (2000)), and in the heterogeneous agent literature (see, notably, De Grauwe & Grimaldi (2006)).

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A Details of the parameters setting

Table 4 gives the values of the parameters explored in the simulations. Those values have been generated using the design of experiments 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 (*see* Sanchez (2005)).

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 4: Design of experiments (typically an Orthogonal Latin Hypercube) for 7 parameters – the last column is irrelevant for Scenarii 1 and 5, the values of σ_ξ are used for Scenarii 2 and 3 and the values of χ are set in Scenario 4.

B Further simulations results

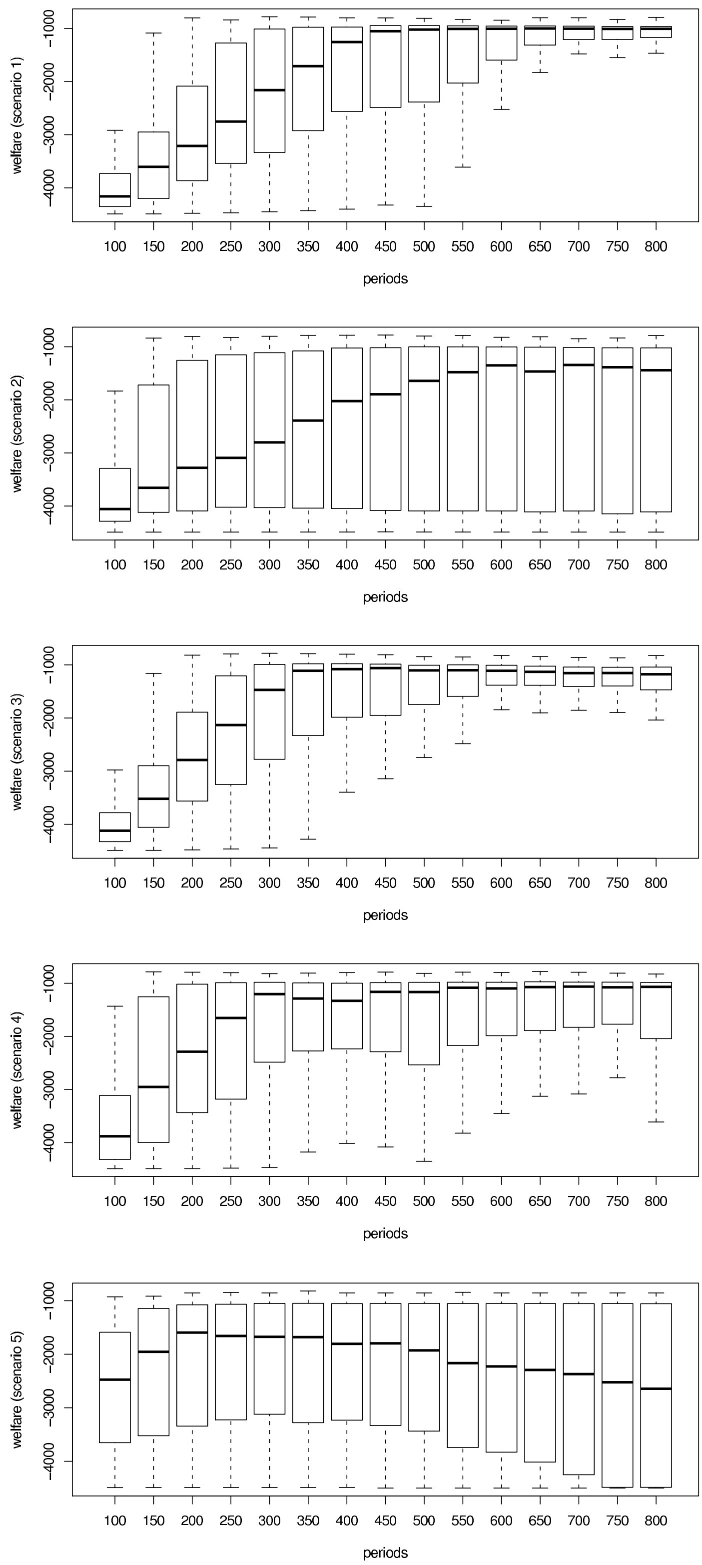

Figure 3: Evolution of the aggregate welfare in the five scenarii – outliers are ruled out.

	scenario 1		scenario 2		scenario 3		scenario 4		scenario 5	
	infGapSqr	*unempSqr*	*infGapSqr*	*unempSqr*	*infGapSqr*	*unempSqr*	*infGapSqr*	*unempSqr*	*infGapSqr*	*unempSqr*
(Intercept)	1.1e-04*** (1e-03)	0.216*** (1e-12)	3e-03 (0.11)	0.114*** (0.004)	5e-05 (0.81)	0.169*** (1e-08)	0.036*** (1e-08)	0.093*** (7e-03)	-0.13*** (<2e-16)	0.55*** (<2e-16)
ϕ_π	2.3e-04*** (4e-05)	-7e-04 (0.966)	-0.0042*** (0.007)	-0.024 (0.648)	3e-03 (0.18)	-0.067 . (0.1)	-0.033*** (2e-08)	0.242*** (1e-06)	0.075*** (2e-06)	-0.121** (0.006)
ϕ_u	3.1e-04*** (3e-08)	0.11* (0.039)	2e-05 (0.99)	-0129 (0.143)	-8e-04 (0.186)	0.202*** (3e-04)	-0.119*** (2e-08)	0.66*** (<2e-16)	0.327*** (<2e-16)	-1.146*** (<2e-16)
ϕ_π^2	-1.4e-04*** (4e-10)	-0.028* (0.019)	0.0014* (0.042)	-0.025 (0.22)	-4e-04 (0.146)	0.012 (0.426)	0.008*** (4e-08)	-0.192*** (<2e-16)	-0.017* (0.022)	-0.027 (0.139)
ϕ_u^2	-4e-04*** (1e-14)	-0.152*** (0.003)	-3e-04 (0.631)	0.062 (0.391)	0.001* (0.041)	-0.183*** (3e-04)	0.101*** (2e-08)	-0.784*** (<2e-16)	-0.275*** (<2e-16)	0.774*** (<2e-16)
$\phi_\pi \phi_u$	2.6e-05 (0.388)	0.07 (0.545)	7e-04 (0.596)	0.058 (0.117)	-4e-04 (0.177)	4e-04 (0.988)	0.037*** (1e-08)	0.184**** (3e-11)	-0.063*** (4e-05)	0.16*** (7e-07)
ρ	3e-05* (0.017)	-0.037*** (3e-04)	-0.001*** (6e-09)	0.003 (0.843)	4e-04** (1e-07)	-0.028*** (8e-03)	-0.014*** (4e-08)	-0.073*** (<2e-16)	0.023*** (3e-04)	0.146*** (<2e-16)
learning (medium)	-2.5e-04*** (<2e-16)	-0.15*** (<2e-16)	-0.002*** (2e-06)	-0.153*** (<2e-16)	-6e-04 . (0.091)	-0.123*** (<2e-16)	0.004*** (3e-06)	-0.196*** (<2e-16)	0.019*** (2e-05)	-0.16*** (<2e-16)
learning (strong)	-2.4e-04*** (<2e-16)	-0.141*** (<2e-16)	-0.001* (0.048)	-0.101*** (2e-10)	-6e-04* (0.026)	0.124*** (<2e-16)	-0.005*** (5e-10)	-0.042 . (0.057)	0.026*** (1e-05)	-0.082*** (1e-06)
σ_{mutK}	-6e-05 (0.161)	0.02 (0.626)	5e-04 (0.718)	0.045 (0.269)	-3e-04 (0.49)	0.026 (0.479)	0.005*** (3e-09)	0.361*** (<2e-16)	0.017 (0.535)	0.146*** (8e-04)
σ_{mutW}	8e-04*** (<2e-16)	-0.0115 (0.163)	0.005*** (2e-13)	0.491*** (<2e-16)	0.001* (0.028)	0.053 (0.138)	0.038*** (2e-06)	0.008 (0.83)	0.242*** (<2e-16)	-0.017 (0.696)
σ_ξ	NA	NA	0.049*** (<2e-16)	2.429*** (<2e-16)	6e-03*** (0.001)	0.677*** (7e-04)	NA	NA	NA	NA
χ	NA	NA	NA	NA	NA	NA	-0.014*** (<2e-16)	-0.091*** (1e-12)	NA	NA
F-stat	61.41*** (<2e-16)	23.56*** (<2e-16)	12.28*** (<2e-16)	36.39*** (<2e-16)	2.125* (0.016)	23.34*** (<2e-16)	40.77*** (<2e-16)	54.65*** (<2e-16)	30.73*** (<2e-16)	120.2*** (<2e-16)
BP-stat	3370 (<2e-16)	354 (<2e-16)	6969 (<2e-16)	821 (<2e-16)	8918 (<2e-16)	643 (<2e-16)	1782 (<2e-16)	700 (<2e-16)	653 (<2e-16)	329 (<2e-16)
adj. R^2	0.199	0.181	0.146	0.133	0.048	0.188	0.2466	0.288	0.108	0.319

Table 5: OLS estimation of the squared inflation gap (*infGapSqr*) and unemployment rate (*unempSqr*) in each scenario (p-value) - Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1