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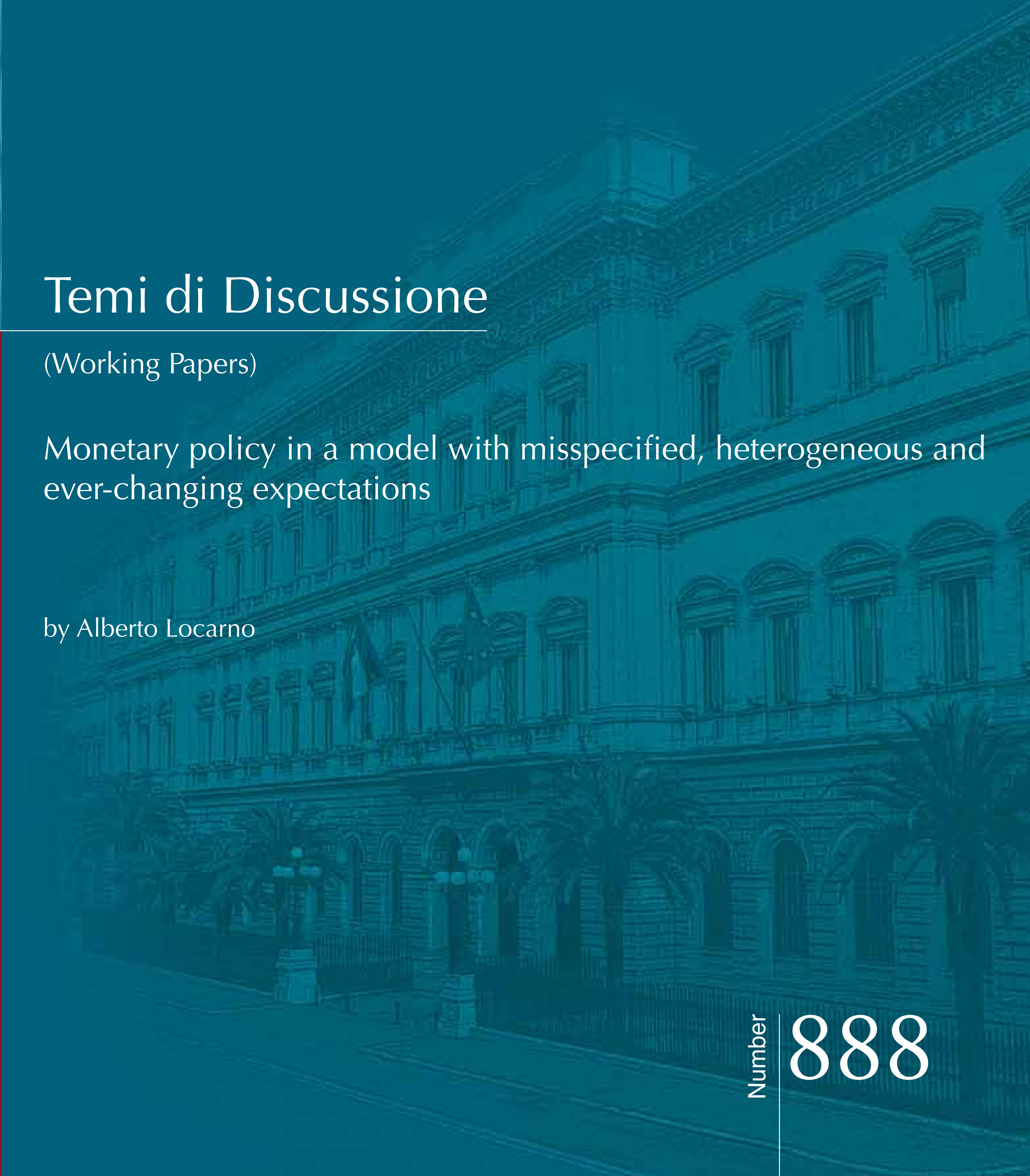

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MONETARY POLICY IN A MODEL WITH MISSPECIFIED, HETEROGENEOUS AND EVER-CHANGING EXPECTATIONS

by Alberto Locarno *

Abstract

The applied literature on adaptive learning has mostly focused on small, linear models, with homogenous expectations. In non-linear models heterogeneous expectations prevail and the process through which agents select (and change) a forecasting model becomes a necessary ingredient of the analysis; moreover, the temporary equilibrium of the learning process approaches an asymptotic limit that may be affected by the communication strategies of the monetary policymaker. The objective of this paper is to assess whether in such a model economy the optimal monetary policy exhibits properties that are similar to those found in the literature for small, linear models. The main results are the following: (1) expectations heterogeneity is an intrinsic feature of the economy: no PLM succeeds in ruling out all the other forecasting models; (2) contrary to previous findings, the monetary policymaker has no incentive to adopt highly inflation-averse policies: too strong a reaction to price shocks increases both inflation and output volatility; (3) partial transparency seems to enhance somewhat welfare (but fully transparent policies do not); (4) a higher degree of transparency calls for stronger inflation aversion.

JEL Classification: E52, E31, D84.
Keywords: bounded rationality, generalised stochastic gradient learning, transparency.

Contents

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1 Introduction and motivation

The vast literature on adaptive learning focuses overwhelmingly on small linear models. Issues like the stability of the equilibrium, the speed of convergence and the dynamics of the learning process are dealt with only for models limited to a handful of equations. And the implications for monetary policymaking are analysed in this very restricted setting, sharply narrowing the range of possible uses. This neglect stems chiefly from the complications of studying stochastic recursive algorithms in large, non-linear systems, but this is unfortunate, because several issues that are relevant only in the context of large-scale models are not paid due attention.

In most of the literature on adaptive learning, it is assumed that the perceived law of motion (PLM) coincides with the minimum state variable (MSV) solution of the corresponding rational expectations equilibrium (REE). This is a convenient simplification that avoids the complexities of dealing with a potential multitude of alternative PLMs and allows straightforward analysis of the asymptotic properties of the learning algorithm. With non-linear models, however, this is no longer possible, since a closed-form MSV solution does not generally exist; still, if the model is medium-sized or large, no unique and commonly accepted linear approximation will be available either, given the large number of state variables that could be included in the forecasting equation.[1]

Absent an MSV solution acting as focal point, agents have to pick out a PLM from a profusion of alternatives, deciding on the basis of some predetermined criterion and taking into account costs of information-gathering and data-processing: different agents end up selecting different forecasting equations and no one sticks to the same PLM indefinitely, preferring to switch based on observed forecasting performances. Evolutionary game theory, which studies the behaviour of large populations who repeatedly engage in strategic interactions, provides the tools for modelling how agents choose among predictors.

Because of degrees-of-freedom constraints, each PLM chosen includes only a handful of explanatory variables and accordingly represents just a projection on a small-dimensional space of the actual law of motion, and the ensuing solution is a restricted-perceptions equilibrium. Misspecified expectations also have non-trivial implications for policymaking.

[1] Assume that the model describing the economy contains l free endogenous variables and n predetermined (endogenous and exogenous) variables; for each endogenous jump variable there are $M(n) = \sum_{j=0}^{n} \binom{n}{j} = 2^n$ alternative linear approximations to the RE solution, an overabundance of options even for small models. If expectations are multi-step ahead, the curse of dimensionality becomes even more uncontrollable, as the right-hand side variables entering the PLM must themselves be forecast: the alternative forecasting models become $M(n) \in O\left(2^{\psi n}\right)$, with $\psi \gg 1$.

Under least squares learning, beliefs become fully rational only if the learning process is E-stable, which depends on the properties of the function $h(\theta) = \lim_{t\to\infty} EQ(\theta, X_t)$, where $Q(\theta, X_t)$ describes how the estimates of the vector θ of coefficents of the PLM is updated every period. When only a subset of the state vector X_t enters the PLM, the asymptotic limit of $EQ(\theta, X_t)$ depends on the covariances between the variables entering the PLM and those characterising the ALM. The main implication is that even asymptotically the equilibrium solution depends on the specific form of the PLM, as does the learning process. Accordingly, if policymakers can affect the shape of the function $Q(\theta, X_t)$, by guiding the choice of agents' PLMs, they can influence economic outcomes. Central banks, for instance, can improve the ability of financial markets to price long-term assets by providing credible information on how monetary policy rates are set, i.e. by choosing the right degree of transparency.

As is apparent from the foregoing, introducing learning in a high-dimensional non-linear model entails many complexities and makes it difficult to generalise the findings of the recent literature on adaptive learning. There are problems of model underparameterisation, heterogeneous beliefs, ever-changing expectations models, and non-ergodicity in expectations formation. The main implication is that the long-run properties of the learning algorithm change; in particular, under suitable but not too restrictive conditions, the asymptotic equilibrium no longer coincides with the REE, but becomes indeterminate, depending on the specific form of the expectations equations.

Not only analytic issues, but also policy prescriptions depend on the structure of the model. For monetary policymaking, Orphanides and Williams (2007) have shown that when agents learn adaptively, the incentives and constraints facing monetary authorities change substantially: compared with the rational expectations case, imperfect knowledge[2] (i) reduces the scope for stabilisation of the real economy; (ii) requires more strongly inflation-averse policies and (iii) increases the inertia in interest rate setting.

Besides the degree of activism, departing from the RE paradigm clearly changes the way transparency affects monetary policy effectiveness. Is it still the case that central banks enhance welfare by providing information to households and firms, or should they rather exploit private information to generate inflation surprises? In the case of the standard New Keynesian model, Berardi and Duffy (2006) show that when the central bank operates under commitment, the effects of transparent policies are unambiguously positive, while under discretion there are cases when opaqueness may ensure better outcomes. Eusepi

[2]Since imperfect knowledge is a precondition for bounded rationality and learning, that expression is used here and henceforth as a synonym of learning and as an antonym of rational expectations, following Orphanides and Williams (2002).

(2005) shows that a sufficient degree of transparency helps make the monetary policy rule robust to expectational errors. These findings are of limited generality, however, since in both papers uncertainty is restricted to the inflation objective and the functional form of the policy rule.[3] In a large model, where non-linearities abound, the flow of information from the monetary authority to the private sector is potentially much richer and the role of communication more important. To a considerable extent the monetary authority can decide on the amount of information to provide to the public so as to influence the equilibrium outcomes.

This paper uses a medium-size model to analyse expectations formation under adaptive learning, heterogeneous beliefs and ever-changing forecasting equations. Empirical rather than analytical results are presented. Two monetary policy issues are used as case studies, the first involving the optimal degree of activism - as in Orphanides and Williams - and the second concerning the benefits associated with transparent policies.

This work makes a number of original contributions.

First, it assumes that in order to anticipate the future path of economic variables, agents can choose among a set of alternative forecasting equations, picking the one with the best track record. Second, it allows agents to have heterogeneous expectations: the share of people selecting a given forecasting model follows a law of motion that is a discrete-time version of the replicator dynamics, implying a gradual movement from worse to better models, unlike another important class of dynamic processes, namely best response dynamics, which involves instantaneous movement to the best-performing strategies. Third, it analyses learning in an economy where expectations have a pervasive role, which is unmatched in the literature: the overwhelming majority of the very few papers studying bounded rationality in large non-linear models introduce learning only in the exchange rate equation.

The paper is organised as follows. The next section presents a survey of the literature on adaptive learning and presents the replicator dynamics developed in evolutionary game theory to model predictor selection; section 3 outlines the model used in the simulations and introduces stochastic gradient learning. Section 4 presents some evidence, obtained by means of simulation, on the impact on monetary policymaking of departing from the assumption that agents are fully rational. Sensitivity analysis is presented in the following part. Section 6 concludes.

[3] In Berardi and Duffy (2006), uncertainty about the monetary policy strategy means that agents do not know whether the lagged output gap is part of the reaction function of the central bank (i.e. whether policy is conducted under discretion or under commitment).

2 The literature

There are very few papers on learning in large non-linear models and they deal mainly with the asymptotic convergence of the learning algorithm, disregarding all the monetary policy implications. Garratt and Hall (1997) use the LBS macromodel, adjusted to include adaptive learning schemes to form expectations on the exchange rate, to study whether the choice of the PLM affects the uniqueness and the stability of the equilibrium and whether the volatility of the transition path depends on how agents learn. The issue is whether adaptive learning is E-stable even when the PLM is overparameterised.[4] Absent analytical results due to the size of the LBS macromodel, they assume that E-stability is achieved when the parameters of the expectations rule cease changing. Garratt and Hall, who use the Kalman filter for the updating of the learning parameters, find that the choice of the PLM modifies the volatility and the speed of convergence of the learning process but obtain less clear-cut evidence on strong E-stability. The end-point for output seems to be the same regardless of the specific form of the PLM, but that for inflation does not. The authors also find that the dynamics and end-value responses of output and inflation are weakly affected by the choice of the expectations rule, but are sensitive to the hyperparameters of the model, i.e. the values of the covariance matrices of the transition and observation equations. The paper is interesting and innovative but has several shortcomings: (i) the forecasting model is the same for all agents; (ii) the learning process relies on hyperparameters that are calibrated rather than estimated; (iii) only exchange rate expectations play a role; (iv) policy issues are entirely neglected; (v) the empirical analysis is based on very short time horizons (less than 10 years).

Beeby, Hall and Henry (2001) go one step further and propose three methods to select a "sensible" PLM when an obvious choice is not available. The first option estimates the effects of a shock to each of the variables on the exchange rate and selects the variables that have a large impact; the second method prescribes computing the rolling correlation (on a 4-quarter window) between the exchange rate and each potential regressor, and ranking the correlations by standard deviations, and choosing the series with the less volatile correlations; the last procedure selects the variables that move most closely with the first few principal components. Beeby, Hall and Henry find also that, regardless of the method used, learning algorithms are quite effective in extracting information from any series, so that the exact form of the rule is unimportant, but they all differ substantially from the RE solution, suggesting that even small deviations from the benchmark of full information

[4] A learning process that converges to the REE even when the PLM is overparameterised is said to be strongly E-stable.

and full rationality may have a strong impact on model properties. An obvious weakness of the paper is that the choice of the best-fitting model is made at the outset once and for all and no heterogeneity in expectations is allowed.

Dieppe *et al.* (2011) represents an original attempt to incorporate learning in a large non-linear model, namely the multi-country model of the European Central Bank: it assumes that agents adopt as PLM the reduced form of the equation whose future value they want to anticipate, disregarding all other information. The coefficients of the forecasting equation are updated by means of the Kalman filter, whose hyperparamaters are calibrated. The paper has strengths and weaknesses: it sheds light on the impact of learning in a model where beliefs are among the main drivers of the equilibrium outcomes but allows no heterogeneity in expectations formation and relies on convoluted and *ad-hoc* assumptions to specify the PLMs.

The existence of differences in expectations, invariably observed in the real world, is the subject of a vast literature. Evans and Ramey (1992) explicitly introduce the costs of calculation into the process of forming expectations: in any period, agents can revise expectations on the basis of a correct model of the economy if they are willing to pay a price, or can keep their expectations unchanged, incurring no cost. Full convergence to rational expectations happens only when the calculation algorithm becomes infinitely fast and resource costs approach zero. Sethi and Franke (1995) show that persistent heterogeneity can be derived on the basis of evolutionary dynamics in the presence of optimisation costs: the use of sophisticated methods is favoured when optimisation costs are low or when the environment has a high degree of exogenous variability. Deterministic and dynamically stable environments favour the use of simpler and cheaper forecasting methods. Dynamic predictor selection is considered by Brock and Hommes (1997) in a model where agents adapt their beliefs over time by choosing from a finite set of different expectations functions on the basis of costs and of a measure of fit, which is publicly available. Brock and Hommes find that a large response to goodness of fit can lead to high-order cycles and chaotic dynamics. The rationale is simple: when agents use the cheaper and less accurate predictors, the steady-state equilibrium is unstable, whereas the costly, sophisticated models are stabilising; near the steady-state it pays to use the cheap predictors, which moves the economy away from the steady-state. For a large enough response, this tension leads to local instability and complex global dynamics. Branch and Evans (2006), working on a similar model, find different results. They assume that agents choose on the basis of the predictive performance among a list of costless, misspecified econometric models and obtain conditions under which there is an equilibrium with agents heterogeneously split between the misspecified models even as the intensity of choice becomes arbitrarily large. Branch and McGough (2008) introduce the replicator dynamics into a model with rationally heterogeneous expectations and show that (i) it is possible to generalise the results of Sethi and Franke to a model with an arbitrarily large number of predictors and (ii) complicated dynamics can arise also in setups that are more general than those of Brock and Hommes. Parke and Waters (2006) study the conditions under which initially heterogeneous beliefs eventually converge to a single forecasting procedure, based on fundamentals and resembling rational expectations. Finally, Berardi (2009) and Guse (2006) analyse the existence and properties of sunspot equilibria in models with heterogeneous expectations, adaptive learning and evolutionary dynamics.

A common feature of the papers focusing on heterogeneity in expectations formation is that they work with highly simplified models that can be solved analytically and are therefore unsuitable for studying policy issues.

The impact on monetary policymaking of assuming boudedly rational agents is the subject of the paper by Orphanides and Williams (2007). The authors examine the performance and robustness of alternative monetary policy rules by estimating a macroeconomic model in which private agents and the central bank possess imperfect knowledge about the true structure of the economy. They find that policies that appear to be optimal under perfect knowledge can perform very poorly when knowledge is incomplete, partly as a result of the persistent policy errors due to misperceptions of the natural rates and partly as a result of the learning process that agents use to form expectations. Efficient policies that take account of private learning and of non-observability of natural rates have two features: first, they call for more aggressive responses to inflation; second, they exhibit a high degree of inertia in the setting of the monetary policy rate. Indeed, difference rules (i.e. rules having on the right-hand-side the lagged interest rate with a coefficient equal to 1), which circumvent the need to rely on uncertain estimates of the natural rates, appear to be robust to potential misspecifications of private sector learning and to the magnitude of variation in natural rates.[5]

The value of communication in monetary policy under imperfect knowledge is studied in several papers, including Ferrero and Secchi (2010), Berardi and Duffy (2006) and Eusepi and Preston (2007). Ferrero and Secchi find mixed results on the impact of transparency on the effectiveness of monetary policymaking: when the central bank reveals information about its own expected interest path, conditions for stability under learning become more

[5]Molnar and Santoro (2010) find similar results in a model where the central bank knows private agents' PLMs and maximises social welfare conditional on them.

stringent and the speed of convergence slows down; on the contrary, the announcement of expected inflation and output gap enlarges the set of policy rules which are consistent with stability and a fast process of convergence. Berardi and Duffy link monetary policy transparency to the specification of the forecast rule adopted by the private sector, unlike the traditional view that equates transparency with more or better information. They adopt the standard cashless, three-equation, New Keynesian model and find that under commitment central bank communication is unequivocally welfare-enhancing, while under discretion the relative value of transparency is ambiguous and depends on target values. Eusepi and Preston find that in a dynamic stochastic general equilibrium model with imperfect knowledge, under no communication the policy rule fails to stabilise macroeconomic dynamics, fostering expectations-driven fluctuations. However, by announcing the details of the policy process, stability is restored: communication permits households and firms to construct more accurate forecasts of future macroeconomic conditions. They further find that if the central bank only announces the desired inflation target, economies with persistent shocks will frequently be prone to self-fulfilling expectations.

While offering significant insights into monetary policymaking, these papers also share two weaknesses, namely the inability to deal with heterogeneous and ever-changing expectations and an overly simplified description of the monetary policy transmission channels.

3 The model

The model used here is a reduced-scale version (a so-called maquette), reproducing the basic features of the Bank of Italy Quarterly Model.[6] The sample that has been used to estimate the model covers a 30-year horizon, from the early 1970s to the late 1990s, before Italy joined the European Monetary Union.

[6]A detailed description of the theoretical underpinnings of the Bank of Italy Quarterly Model is in Terlizzese (1994) and Busetti *et al.* (2005). The model is Keynesian in the short run, with the level of economic activity primarily determined by aggregate demand, and neo-classical in the long run. Along a steady-state growth path, the dynamics of the model stem solely from capital accumulation, productivity growth, foreign inflation and demographics; in the short run, a number of additional features matter, namely (i) the stickiness of prices and wages, (ii) the putty-clay nature of capital and (iii) expectational errors. Agents are not fully rational and form expectations by projecting the variables of interest on a subset of predetermined variables; however, unlike adaptive learning, the coefficients of the PLM are not updated whenever new observations are available. In equilibrium - i.e. when no shocks affect the model, expectations are fulfilled and all adjustment processes are completed - the model describes a full-employment economy, in which output, employment and the capital stock are consistent with an aggregate production function, relative prices are constant and inflation equals the exogenous rate of growth of foreign prices. Money is neutral, though not super-neutral. In the taxonomy proposed by Fukač and Pagan (2009), the Bank of Italy Quarterly Model belongs to the 2^{nd} Generation, but shares some of the features of 3^{rd} (i.e. stock-flow consistency and prominence of steady-state properties).

The behavioural equations are consistent with maximising agents, but the model is not *strictu sensu* microfounded,[7] since it does not contain all the cross equations restrictions that hold when agents are fully rational, and its structural equations are not tied down exclusively by taste and technology parameters.[8] Identification is achieved by imposing that the responses of model variables to exogenous shocks are consistent with stylised facts and theoretical presumptions. Like the model in Orphanides and Williams (2007), its main merit is to fit the sample data reasonably well. The learning framework accommodates the Lucas critique, in the sense that expectations formation is endogenous and adjusts to changes in policy or in the structure of the economy,[9] and accordingly it is legitimate to measure the welfare implications of competing interest-rate rules.

The maquette has some 90 endogenous and 70 exogenous variables. Taking into account expectations formation, the model is described by the following set of vector equations:

$$\begin{aligned} \widetilde{y}_t &= f_1\left(\widehat{E}_{t-1}\widetilde{y}_t, \widehat{E}_{t-1}\widetilde{y}_{t+1}, ..., \widehat{E}_{t-1}\widetilde{y}_{t+h}, \widehat{y}_t, x_t; \Psi_1\right) + u_{1,t} \\ \widehat{y}_t &= f_2\left(x_t; \Psi_2\right) + u_{2,t} \\ w_t &= f_3\left(w_{t-1}, w_{t-2}, ..., w_{t-q}; \Psi_3\right) + u_{3,t} \end{aligned} \tag{1}$$

where $\widetilde{y}_t$ and $\widehat{y}_t$ are, respectively, the vectors of free and predetermined endogenous variables; w_t indicates the set of exogenous variables, including the intercept; $u_{j,t}$ $(j = 1, 2, 3)$ are innovations; x_t is the vector that assembles w_t and all the lags of $\widetilde{y}_t$, $\widehat{y}_t$ and w_t; the matrices Ψ_j $(j = 1, 2, 3)$ are collections of parameters; $\widehat{E}$ is the (nonrational) expectations operator; h represents the maximum lead with which free variables enter the system; q is the order of the possibly non-linear autoregression for the vector w_t.

Beliefs, which have a direct impact on $\widetilde{y}_t$ but affect $\widehat{y}_t$ only indirectly (through lags of $\widetilde{y}_t$), enter the model in several ways: ex-ante real interest rates affect the demand for both consumption and capital goods; next-period expected inflation drives current-period wage claims; beliefs about future price developments affect the policy interest rates[10] and the

[7]Many of the econometric models used for forecasting purposes by central banks are not microfounded. In the euro area, most central banks except the Finnish use semi-structural models like the Bank of Italy's; in the United States, the FRB/US, FRB/MCM and FRB/World, which are are not truly structural, are still nevertheless the prime large-scale macro models currently in use at the Fed. See Fagan and Morgan (2005) for the euro area and Pescatori and Zaman (2011) for the United States.

[8]Incidentally, one could convincingly object that a model that assumes imperfect knowledge should **not** feature structural equations that are consistent with full rationality.

[9]Orphanides and Williams (2004) use the expression "noisy rational expectations" as a synonym of adaptive learning.

[10]The short-term (policy) interest rate depends on the current unemployment gap and on next-period inflation, the latter variable expressed in terms of deviations from target inflation. Some inertia in the policy instruments is allowed by including the lagged interest rate among the arguments of the policy rule.

term structure, which is modelled according to the expectations hypothesis;[11] anticipated changes in the nominal exchange rate bear upon competitiveness and the terms of trade. Moreover, beliefs play a direct role in shaping policy decisions, since natural rates are non-observable and the central bank has to estimate them, before deciding on the proper monetary stance.

The monetary policy transmission mechanism, which is described in detail, works in three phases: first, a change in the policy interest rate spills over to other segments of the capital market, affecting financial asset returns (namely yields on long-term bonds and exchange rates); next, the movements in financial prices interact with the spending behaviour of households and firms; and finally, the change in output and unemployment gaps, driven by the response of consumption and investment, induces wages and prices to adjust to restore the equilibrium. The adjustment process induces modifications in the composition of private and public sector balance sheets, which in turn exert second-round effects on interest rates, thus setting the stage for the response of aggregate demand and supply: the interaction between the real and the financial side of the economy continues until a new equilibrium is reached.

Interest rates affect output through five transmission channels: (i) the cost-of-capital channel, which works through changes in the optimal capital-output ratio; (ii) the substitution-effect-in-consumption channel, involving the response to financing costs of the relative price of present as opposed to future consumption; (iii) the income and cash-flow channel, based on how capital income flows affect disposable income, whose effects depend on the financial structure of the economy and on borrowers' and lenders' relative propensity to spend; (iv) the wealth channel, that takes into account how fluctuations in borrowing conditions affect the discounted value of future expected payoffs of physical and financial assets; and (v) the exchange rate channel, which measures how fluctuations in exchange rates – triggered by the uncovered interest-rate parity condition – affect competitiveness, the price of imported goods, aggregate demand and inflation.

3.1 The learning mechanism

Bounded rationality may be modelled by using recursive least squares (RLS) learning. A convenient alternative to RLS is the stochastic gradient (SG) algorithm, whose main advantage is that it does not rely on information on the second moments of the variables in the forecasting equation. SG learning, which under standard conditions is consistent

[11] Long-term interest rates are assumed to be a weighted average of current and future short-term rates, with the term spread constant.

but not efficient, has been found to work well in complex environments, suggesting that it has robustness properties that RLS lacks. The main drawbacks are: (i) it is not invariant with respect to changes in the units of measurement of the variables in the PLM and (ii) E-stability does not always imply convergence of SG learning.

Recently, Evans et al. (2010) have proposed a generalisation of the SG algorithm, called Generalised Stochastic Gradient (GSG) learning, which solves the invariance problem. They also show that the GSG algorithm has other important justifications: first, it approximates a Bayesian estimator in models where parameters drift; second, it is a maximally robust optimal prediction rule when there is parameter uncertainty; third, though conditions for the stability of generalised stochastic gradient learning differ in general from those governing stability under least squares learning, E-stability in most cases remains a necessary condition for asymptotic convergence of GSG learning.

In all the experiments described in this paper, expectations are modelled by means of a GSG algorithm, as described in (2).

$$\begin{array}{lcll} \widehat{E}^{j}_{t-1}\widetilde{y}_{i,t} & = & \varphi^{iT}_{j,t-1}D^{j}_{i}x_t & j\in\{0,,..,k_i\} \\ \varphi^{i}_{j,t} & = & \varphi^{i}_{j,t-1}+\gamma_t\Gamma D^{j}_{i}x_t\left(y_t-\varphi^{iT}_{j,t-1}D^{j}_{i}x_t\right) & \\ x^{i}_{j,t} & = & x^{i}_{j,t-1}g\left(\widetilde{y}_{i,t}-\widehat{E}^{j}_{t-1}\widetilde{y}_{i,t},\widetilde{y}_{i,t}-\widehat{E}_{t-1}\widetilde{y}_{i,t},\right) & g_1<0,g_2>0 \\ \widehat{E}_{t-1}\widetilde{y}_{i,t} & = & \sum_{j=1}^{k_i}x^{i}_{j,t-1}\widehat{E}^{j}_{t-1}\widetilde{y}_{i,t} & \end{array} \quad (2)$$

$\widetilde{y}_{i,t}$ indicates the i^{th} free variable, γ_t is the gain sequence and $\varphi^{i}_{j,t}$ represents the vector of coefficients of the PLM estimated as of time $t-1$. The first equation represents the j^{th} PLM for variable $\widetilde{y}_{i,t}$: as agents have imperfect knowledge, they use only a subset of the state vector x_t, i.e. $D^{j}_{i}x_t$, to make predictions;[12] moreover, being uncertain about the data generating process, they use k_i forecasting equations to predict $\widetilde{y}_{i,t}$, switching from one to another depending on some measure of fit. The share of individuals choosing model $j\in\{1,2,...,k_i\}$ is equal to $x^{i}_{j,t}$, which is a function of its forecasting accuracy $\left(\widetilde{y}_{i,t}-\widehat{E}^{j}_{t-1}\widetilde{y}_{i,t}\right)$ relative to the average performance of all forecasting models $\left(\widetilde{y}_{i,t}-\widehat{E}_{t-1}\widetilde{y}_{i,t}\right)$. The last equation in (2) states that the expected value of $\widetilde{y}_{i,t}$ is the weighted average of the forecasts of the k_i PLMs.

Though the structural relationships among variables are in general non-linear, the PLMs are assumed to be linear. The gist of the GSG algorithm is captured by the (fixed) matrix Γ, which does not coincide with the inverse of the second-moment matrix of the regressors (as in recursive least squares) and is not equal to the identity matrix (as in the gradient

[12] D^{j}_{i} is a selector matrix, i.e. a matrix whose rows have all zeros and a single 1.

learning algorithm).
Stability is governed by the differential equation

$$\frac{d\varphi}{d\tau} = \Gamma M_x \left(T\left(\varphi\right) - \varphi\right) \tag{3}$$

where $T\left(\varphi\right)$ is the (expected value of the) ALM, $M_x = \lim_{t\to\infty} ED_i x_t x_t^T D_i^T$ and τ is notional time. When both Γ and M_x are positive definite, the fixed point of (3) is the REE $\overline{\varphi}$ and (local) stability is achieved when the eigenvalues of the linearisation of the above matrix differential equation[13] have negative real parts. With RLS learning, the term ΓM_x cancels out and (local) stability depends only on the eigenvalues of the Jacobian of $T\left(\varphi\right)-\varphi$, i.e. $DT-I$. In general, the stability conditions for the RLS and GSG algorithms do not coincide and neither implies the other; they become equivalent when the matrix $DT - I$ is H-stable or, alternatively, when Γ is such that $\Gamma M_x = I$.[14]
In all the simulations described here, the scaling matrix Γ is set equal to the inverse of the sample covariance matrix of the regressors estimated on historical data.

3.2 Heterogeneous expectations and predictor selection

If agents can pick one out of a large number of forecasting equations, none of which is clearly superior, some problems arise: first, expectations can be heterogenous, since there is no guarantee that everyone will choose the same PLM (or the same sample period); second, agents may elect to change their forecasting equation if they perceive its accuracy as poor; third, several PLMs can coexist asymptotically, though enough observations are available to tell which performs best.
Evolutionary game theory provides the tool for constructing an explicit model of the process by which agents select the strategy to play in a repeated game.[15] In the typical evolutionary game-theoretic model, there is a large population of agents whose payoff is a function not only of their own strategy but also of other players' behaviour: if an agent can maximise and knows other players' actions, then he can choose the best response; if he does not, he can learn from the observed history of play, which conveys information about how the opponents are likely to play and suggests which strategies are most successful.

[13] The linearisation of the RHS of equation (3) is $\left(\Gamma M_x \otimes I\right)\left(DT^{'} - I\right)$, where DT is the Jacobian of the vectorised mapping $T\left(\varphi\right)$.

[14] A matrix C, whose eigenvalues have negative real parts, is said to be H-stable if the eigenvalues of HC have negative real parts whenever the matrix H is positive definite. See Evans *et al.* (2010), in particular Proposition 3 and 4.

[15] Mailath (1998) and Samuelson (2002) are short but very good surveys of evolutionary game theory; Weibull (1995) is a comprehensive and detailed reference.

Agents gradually learn to play an equilibrium if they play the same game (or similar games) repeatedly: once all players have learned how their opponents are playing, and if all are maximising, then they converge to a Nash equilibrium. But how do they reach such an equilibrium? The simplest evolutionary model one could use is the replicator dynamics, which specifies that agents tend to select strategies that do better than the population average and discard those that do worse.

Evolutionary models exhibit learning as a primary ingredient, but are not structural models of learning or bounded rationality: individuals are not explicitly modelled and are treated as naive learners, who do not understand that their behaviour can affect the future play of their opponents and do not take into account that their competitors behave just like them. Agents do not look for patterns in historical data but behave as if the world is stationary, presuming that other players' experience is relevant for them, which justifies imitation.

Here I use the discrete-time version of the replicator dynamics. The economy is populated by a large but finite number of individuals, who play strategy $i \in \{1, 2, .., K\}$ in a symmetric two-player game with mixed-strategy simplex $\Delta \subset \mathbb{R}^{K-1}$. Let $p_t^i \geqslant 0$ be the number of individuals who currently select pure strategy i (i.e. who choose model i as a predictor for variable y_t) and let $p_t = \sum_{i=1}^{K} p_t^i > 0$ be the total population; the share of agents adopting strategy i is accordingly defined as $x_t^i \equiv \frac{p_t^i}{p_t}$ and the vector of predictor proportions (also referred as population state) is $\mathbf{x}_t = \begin{bmatrix} x_t^1 & x_t^2 & ... & x_t^K \end{bmatrix}^T \in \Delta$, showing that a population state is formally identical with a mixed strategy. The payoff to any pure strategy i at a random match when the population is in state $\mathbf{x}_t \in \boldsymbol{\Delta}$ is $u\left(e_t^i, \mathbf{x}_t\right)$, where e^i is a vector with 1 in the i^{th} position and 0 elsewhere, representing a pure strategy (i.e. a vertex of the simplex Δ); the associated average payoff is $\sum_{i=1}^{K} x_t^i u\left(e_t^i, \mathbf{x}_t\right)$. The p^is evolve according to the following laws of motion:

$$p_t^i = \left(g + u\left(e_{t-1}^i, \mathbf{x}_{t-1}\right)\right) p_{t-1}^i, \forall i$$

where g represents the (steady-state) growth rate of the population (the so-called background net birthrate), which implies that

$$p_t = \sum_{i=1}^{K} x_{t-1}^i \left(g + u\left(e_{t-1}^i, \mathbf{x}_{t-1}\right)\right) p_{t-1} = \left(g + \sum_{i=1}^{K} x_{t-1}^i u\left(e_{t-1}^i, \mathbf{x}_{t-1}\right)\right) p_{t-1}$$

The discrete-time replicator dynamics is accordingly:

$$x_t^i = \frac{g+u\left(e_{t-1}^i, \mathbf{x}_{t-1}\right)}{g+\sum_{i=1}^{K} x_{t-1}^i u\left(e_{t-1}^i, \mathbf{x}_{t-1}\right)} x_{t-1}^i$$

For the vector $\mathbf{x}_t$ to be a proper population state, it must belong to the unit simplex in $\mathbb{R}^{K-1}$ and each of its elements must satify the constraint that $0 \leqslant x_t^i \leqslant 1$: both conditions are clearly satisfied in the standard case when $u(\cdot, \mathbf{x})$ and g are positive.[16]
In the empirical section an exponential transformation of the mean-square error is used as the payoff function, namely $u(e_t^i, \mathbf{x}_t) = \exp[-\lambda(MSE_t^i + C_i)]$,[17] where C_i is the cost of using model i and $MSE_t^i = (1 - \omega_t) MSE_{t-1}^i + \omega_t \left(y_t - \widehat{E}_{t-1}^i y_t\right)^2$, with $\omega_t \in \left\{\frac{1}{t}, \varpi\right\}$ and $\widehat{E}_{t-1}^i$ being the (conditional) expectations operator based on model i. For simulation purposes, the parameters of the replicator dynamics have been given the following values: $g = .02$; $\lambda = 1000$; $C_i = 0$, $\forall i$.

3.3 The role of expectations

Expectations play a pervasive role in the model: they enter the price- and wage-setting equations, affect monetary policy decisions and drive prices in asset markets. Both the central bank and private agents are assumed to be boundedly rational: the monetary authority learns about inflation and the natural rates of interest and unemployment; households and firms learn about the policy rate, inflation and the exchange rate. It is assumed that the central bank does not consciously attempt to influence the speed of learning by adjusting the degree of activism in policymaking.[18]
Unlike the central bank, which uses a single forecasting model for each variable of interest, the private sector employs several predictors jointly. There is no way to avoid unwarranted assumptions in specifying the multiple and mutually coexisting forecasting models that boundedly rational agents use. The problem is how to constrain the information set in an intelligent way, choosing among the innumerable possible ways of doing so. The solution adopted here is to consider only specifications that are sensible economically and that generate predictions that track realisations reasonably well: goodness of fit is assessed using the criteria proposed in Beeby, Hall and Henry (2001).
The central bank is assumed to set the policy instrument[19] i_t according to the following

[16] Branch and McGough (2008) use a rule for updating predictor proportions that is state-contingent. They distringuish the strategies $j \in B(x_{t-1})$ that perform worse than average from the strategies $i \in G(x_{t-1})$ that perform better. To impose that $\sum_i x_t^i = 1$, they compute $\sum_{j \in B(x_{t-1})} |\Delta x_t^j|$ and distribute that amount to the strategies $i \in G(x_{t-1})$ in proportion to their payoffs.

[17] A convex mapping like the exponential function does not reorder the ranking of the payoffs, but alters players' reaction to small and large forecast errors.

[18] Ellison and Valla (2001) show that strategic interactions create a connection between the activism of the central bank and the volatility of inflation expectations: the latter reacts to the former because an activist policy produces more information, helping the learning process.

[19] The Bank of Italy Quarterly Model includes several interest rates. To keep the size of the maquette small, all money market rates were reduced to one - the monetary policy instrument - defined as the

reaction function:

$$i_t = \rho i_{t-1} + (1-\rho)\left[r^* + \overline{\pi} + \alpha_\pi\left(\widehat{E}^{CB}_{t-1}\pi_{t+1} - \overline{\pi}\right) - \alpha_u\left(u_t - u^*\right)\right] \quad (4)$$

where $\widehat{E}^{CB}$ indicates central bank expectations and r^* and u^* are, respectively, the non-observable natural real interest rate and unemployment rate, which the policymaker seeks to estimate by computing the sample average of the corresponding observables. The central bank's PLMs for π, r^* and u^* are:

$$\begin{cases} \widehat{E}^{CB}_{t-1}\pi_t &= \pi_{t-1} + \alpha_{1,t-1}\Delta i_{t-1} + \alpha_{2,t-1}\Delta\pi_{t-1} \\ \widehat{E}^{CB}_{t-1}r^*_t &= r^*_{t-1} + \gamma_t\left(i_{t-1} - \pi_{t-1} - r^*_{t-1}\right) \\ \widehat{E}^{CB}_{t-1}u^*_t &= u^*_{t-1} + \gamma_t\left(u_{t-1} - u^*_{t-1}\right) \end{cases} \quad (5)$$

where γ_t is the gain sequence.[20] The PLM for inflation is admittedly simple, but it captures the idea that inflation is sticky and depends on the monetary policy stance. The specification was chosen because it minimises the standard error of the regression in a two-variable equation and exhibits a high and stable correlation with survey measures of inflation expectations.[21] The specification is in first differences, so that it is consistent with a time-varying inflation objective, reflecting the historical experience of monetary policymaking in Italy in the 1970s and 1980s.

According to the PLM chosen, the central bank's expectations for next-period inflation are equal to:

$$\widehat{E}^{CB}_{t-1}\pi_{t+1} = A_{1,t-1}\pi_{t-1} + A_{2,t-1}\pi_{t-2} + A_{3,t-1}\Delta i_t + A_{4,t-1}\Delta i_{t-1} \quad (6)$$

weighted average of the yields of 3, 6, and 12-month Treasury bills.

[20] In the case of decreasing gain $\gamma_t = \frac{1}{t}$, while for perpetual learning $\gamma_t = \overline{\gamma}$.

[21] Besides the short-term interest rate and lagged inflation, the following variables were considered as eligible regressors: (1) the output gap; (2) the growth rate of GDP; (3) the unemployment rate; (4) the oil price; (5) the nominal effective exchange rate. Absent a unique procedure for selecting the regressors, an evaluation was made on the basis of four criteria: (1) the standard error of the regression; (2) the correlation between $\widehat{E}^{CB}_{t-1}\pi_t$ and survey measures of inflation expectations; (3) the rolling correlation (with a 4-year window) with actual inflation; (4) the co-movement with the 1^{st} and 2^{nd} principal components. The last two criteria are suggested by Beeby *et al.* (2001) on the grounds that one picks the variables whose correlation with inflation is high and stable and the other helps select regressors that do not overlap in the amount of predictive information. In principle, the maximisation of the correlation between $\widehat{E}^{CB}_{t-1}\pi_t$ and survey-based inflation expectations is what one should be concerned with in choosing the specification of the PLM; in practice, survey data are not a fully satisfactory proxy of households' and firms' anticipations of future price dynamics. Principal component analysis suggests that two factors explain most of the sample variance and hence two-regressor models are considered. Among the specifications featuring only two regressors, that with lagged inflation and the policy interest rate (i) minimises the standard error of the regression; (ii) exhibits the second-highest correlation with survey-based expected inflation; (iii) has the highest and most stable correlation with actual inflation and (iv) presents regressors moving closely with the first principal component.

where $A_{1,t-1} = \frac{1-\alpha^3_{2,t-1}}{1-\alpha_{2,t-1}}$, $A_{2,t-1} = 1 - A_{1,t-1}$, $A_{3,t-1} = \alpha_{1,t-1}$ and $A_{4,t-1} = (1+\alpha_{2,t-1})\,\alpha_{1,t-1}$. Individuals neither observe the central bank's inflation expectations nor compute model-based estimates. Rather, they pick a forecast out of a limited number of alternatives, sold for a fee C_k by professional forecasters, who use their own model to estimate the future value of economic variables. Absent any empirical evidence for estimating the cost parameters C_k, it is assumed that $C_k = 0$, $\forall k$, so that the only factor affecting the choice of a given forecasting model is accuracy. The relative performance of each model, measured by its mean square error, is common knowledge and in each period agents buy the forecast with the best track record.

Concerning inflation predictions, it is assumed that agents choose among the following 5 predictors:

$$\begin{aligned}
\widehat{E}^{\pi 1}_{t-1}\pi_t &= \vartheta^1_{2,t-1}\Delta y_{t-1} + \vartheta^1_{3,t-1}\pi_{t-1} + \vartheta^1_{4,t-1}\pi_{t-2} + \vartheta^1_{5,t-1}\Delta i_{t-1} \\
\widehat{E}^{\pi 2}_{t-1}\pi_t &= \vartheta^2_{0,t-1} + \vartheta^2_{1,t-1}u_{t-1} \\
\widehat{E}^{\pi 3}_{t-1}\pi_t &= \vartheta^3_{0,t-1} + \vartheta^3_{2,t-1}\Delta y_{t-1} + \vartheta^3_{6,t-1}\Delta e_{t-1} \\
\widehat{E}^{\pi 4}_{t-1}\pi_t &= \vartheta^4_{0,t-1} + \vartheta^4_{7,t-1}\Delta ulc_{t-1} + \vartheta^4_{8,t-1}\Delta p^M_{t-1} \\
\widehat{E}^{\pi 5}_{t-1}\pi_t &= \vartheta^5_{0,t-1} + \vartheta^5_{3,t-1}\pi_{t-1}
\end{aligned}$$

where $\widehat{E}^{\pi k}_{t-1}$ is the expectations operator referring to the k^{th} inflation predictor; y_t is output; u_t the unemployment rate; e_t is the exchange rate; ulc_t unit labour costs; p^M_t the import deflator.[22] The first equation captures the idea that inflation is sticky and responds to changes in the monetary policy stance and in output growth; the second is a simplified Phillips curve; the third and fourth equations model consumer price dynamics as the sum of domestic costs, proxied either by output growth or by changes in unit labour costs, and foreign inflation, measured by the exchange rate or, alternatively, the import deflator; the last equation models inflation as an AR(1) process.

Private sector inflation expectations are equal to $\widehat{E}^{\pi}_{t-1}\pi_t = \sum_{j=1}^{5} x^j_{t-1}\widehat{E}^{\pi j}_{t-1}\pi_t$, i.e.

$$\begin{aligned}
\widehat{E}^{\pi}_{t-1}\pi_t &= \Theta_{0,t-1} + \Theta_{1,t-1}u_{t-1} + \Theta_{2,t-1}\Delta y_{t-1} + \Theta_{3,t-1}\pi_{t-1} + \Theta_{4,t-1}\pi_{t-2} \\
&+ \Theta_{5,t-1}\Delta i_{t-1} + \Theta_{6,t-1}\Delta e_{t-1} + \Theta_{7,t-1}\Delta ulc_{t-1} + \Theta_{8,t-1}\Delta p^M_{t-1}
\end{aligned}$$

where $\Theta_{0,t-1} = \sum_{j=2}^{5} x^j_{t-1}\vartheta^j_{0,t-1}$, $\Theta_{1,t-1} = x^2_{t-1}\vartheta^2_{1,t-1}$, $\Theta_{2,t-1} = x^1_{t-1}\vartheta^1_{2,t-1} + x^3_{t-1}\vartheta^3_{2,t-1}$, $\Theta_{3,t-1} = x^1_{t-1}\vartheta^1_{3,t-1} + x^5_{t-1}\vartheta^5_{3,t-1}$, $\Theta_{4,t-1} = x^1_{t-1}\vartheta^1_{4,t-1}$, $\Theta_{5,t-1} = x^1_{t-1}\vartheta^1_{5,t-1}$, $\Theta_{6,t-1} = x^3_{t-1}\vartheta^3_{6,t-1}$, $\Theta_{7,t-1} = x^4_{t-1}\vartheta^4_{7,t-1}$ and $\Theta_{5,t-1} = x^4_{t-1}\vartheta^4_{5,t-1}$.

[22] All variables but u_t are log transformations.

Individuals rely upon professional forecasters for (short-term) interest rate expectations as well; they are aware which rate is the central bank's instrument, but they do not know either the precise form of the interest-rate rule or how natural rates are estimated. It is assumed that agents can choose among the following 7 predictors:

$$\begin{aligned}
\widehat{E}^{i1}_{t-1} i_t &= \theta^1_{0,t-1} + \theta^1_{1,t-1} u_{t-1} + \theta^1_{3,t-1} \pi_{t-1} \\
\widehat{E}^{i2}_{t-1} i_t &= \theta^2_{0,t-1} + \theta^2_{1,t-1} u_{t-1} + \theta^2_{3,t-1} \pi_{t-1} + \theta^2_{4,t-1} i_{t-1} \\
\widehat{E}^{i3}_{t-1} i_t &= \theta^3_{0,t-1} + \theta^3_{1,t-1} u_{t-1} + \theta^3_{3,t-1} \widehat{E}^{i3}_{t-1} \pi_{t+1} + \theta^3_{4,t-1} i_{t-1} \\
\widehat{E}^{i4}_{t-1} i_t &= \theta^4_{0,t-1} + \theta^4_{2,t-1} \widehat{E}^{i4}_{t-1} \Delta y_t + \theta^4_{3,t-1} \widehat{E}^{i4}_{t-1} \pi_{t+1} + \theta^4_{4,t-1} i_{t-1} \\
\widehat{E}^{i5}_{t-1} i_t &= \theta^5_{0,t-1} \\
\widehat{E}^{i6}_{t-1} i_t &= \theta^6_{0,t-1} + \theta^6_{2,t-1} \widehat{E}^{i6}_{t-1} \Delta y_t + \theta^6_{3,t-1} \widehat{E}^{i6}_{t-1} \pi_{t+1} + \theta^6_{4,t-1} i_{t-1} + \theta^6_{5,t-1} \widehat{E}^{i6}_{t-1} \Delta e_t \\
\widehat{E}^{i7}_{t-1} i_t &= \theta^7_{0,t-1} + \theta^7_{4,t-1} i_{t-1}
\end{aligned} \tag{7}$$

where $\widehat{E}^{ij}_{t-1}$ is the expectations operator referring to the j^{th} interest-rate predictor. Models 1 to 4 reflect the main finding of the model comparison project conducted by Bryant, Hooper and Mann (1993), namely that effective interest-rate rules react to both inflation and economic slackness, the latter measured in terms of the unemployment rate or, alternatively, the GDP growth rate. The four specifications differ also with regard to policy inertia and the timing of the arguments of the interest-rate rule. Models 5 and 7 capture the naive belief that the central bank seeks to keep the nominal interest rate constant, allowing at most temporary deviations from the target level. Equation 6 includes the exchange rate among the variables affecting the monetary policy stance, which is not uncommon for small open economies.[23]

In some of the above forecasting models, predictions of future variables appear among the regressors, which in principle would require specifying additional (and possibly multiple) PLMs for each of them. To simplify matters, the following solution has been adopted: expectations of the right-hand-side variables are obtained under the assumption that they evolve according to simple $AR(1)$ processes, namely $\widehat{E}_{t-1} z_t = \psi^z_{0,t-1} + \psi^z_{1,t-1} z_{t-1}$, where z_t is, alternatively, π_t, u_t, Δy_t or Δe_t.[24]

The average expected short-term interest rate at time t is therefore equal to

$$\begin{aligned}
\widehat{E}^{i}_{t-1} i_t &= \sum_{k=1}^{7} x^k_{t-1} \widehat{E}^{ik}_{t-1} i_t \\
&= \Omega_{0,t-1} + \Omega_{1,t-1} u_{t-1} + \Omega_{2,t-1} \Delta y_{t-1} \\
&+ \Omega_{3,t-1} \pi_{t-1} + \Omega_{4,t-1} i_{t-1} + \Omega_{5,t-1} e_{t-1}
\end{aligned} \tag{8}$$

[23] Bryant, Hooper and Mann (1993) find that interest-rate rules that react to the exchange rate perform worse on average than those that neglect it. Taylor and Williams (2009) make a similar claim.

[24] It is implicitly assumed that the professional forecasters predicting the short-term interest rate are not the same as those forecasting inflation.

where

$$
\begin{aligned}
\Omega_{0,t-1} &= \sum_{k=1}^{7} x_{t-1}^{k}\theta_{0,t-1}^{k} + \psi_{0,t-1}^{\Delta y}\sum_{k\in\{4,6\}} x_{t-1}^{k}\theta_{2,t-1}^{k} \\
&+ \left(1+\psi_{1,t-1}^{\pi}\right)\psi_{0,t-1}^{\pi}\sum_{k\in\{3,4,6\}} x_{t-1}^{k}\theta_{3,t-1}^{k} + \psi_{0,t-1}^{\Delta e}x_{t-1}^{6}\theta_{5,t-1}^{6} \\
\Omega_{1,t-1} &= \sum_{k=1}^{3} x_{t-1}^{k}\theta_{1,t-1}^{k} \\
\Omega_{2,t-1} &= \psi_{1,t-1}^{\Delta y}\sum_{k\in\{4,6\}} x_{t-1}^{k}\theta_{2,t-1}^{k} \\
\Omega_{3,t-1} &= \left(\psi_{1,t-1}^{\pi}\right)^{2}\sum_{k\in\{3,4,6\}} x_{t-1}^{k}\theta_{3,t-1}^{k} \\
\Omega_{4,t-1} &= \sum_{k\in\{2,3,4,6\}} x_{t-1}^{k}\theta_{4,t-1}^{k} \\
\Omega_{5,t-1} &= \psi_{1,t-1}^{\Delta e}x_{t-1}^{6}\theta_{5,t-1}^{6}
\end{aligned}
$$

Expectations of short-term interest rates form part of the equation of the yield curve. According to the expectations hypothesis, k-year bond yields are equal to the k-year moving average of current and the future short-term interest rates plus a constant term premium that agents estimate using the historical mean. To prevent forecast errors from accumulating when computing multi-step ahead interest-rate expectations, the term premium is corrected for the mean difference between expected and actual past policy rates:

$$
\widehat{E}_{t-1}term_{t} = term_{t-1} + \gamma_{t}\left[\left(i_{t-1}^{L} - i_{t-1}\right) + \frac{1}{6}\sum_{j=1}^{6}\xi_{t-j} - term_{t-1}\right] \tag{9}
$$

where $\xi_{t-j} \equiv i_{t-1} - \widehat{E}_{t-1-j}i_{t-1}$ measures the surprise on the policy interest rate.
By taking the j^{th} lead of equation (8), for $1 \leqslant j \leqslant 5$, and replacing all non-predetermined variables, one obtains the following expression for $\widehat{E}_{t-1}i_{t+j}$:

$$
\begin{aligned}
\widehat{E}_{t-1}^{i}i_{t+j} &= \Omega_{0,t-1}^{j} + \Omega_{1,t-1}^{j}u_{t-1} + \Omega_{2,t-1}^{j}\Delta y_{t-1} \\
&+ \Omega_{3,t-1}^{j}\pi_{t-1} + \Omega_{4,t-1}^{j}i_{t-1} + \Omega_{5,t-1}^{j}\Delta e_{t-1}
\end{aligned} \tag{10}
$$

where

$$
\begin{aligned}
\Omega_{0,t-1}^{j} &= \Omega_{0,t-1} + \Omega_{1,t-1}\frac{1-\left(\psi_{0,t-1}^{u}\right)^{j+1}}{1-\psi_{0,t-1}^{u}} + \Omega_{2,t-1}\frac{1-\left(\psi_{0,t-1}^{\Delta y}\right)^{j+1}}{1-\psi_{0,t-1}^{\Delta y}} \\
&+ \Omega_{3,t-1}\frac{1-\left(\psi_{0,t-1}^{\pi}\right)^{j+1}}{1-\psi_{0,t-1}^{\pi}} + \Omega_{4,t-1}\Omega_{0,t-1}^{j-1} + \Omega_{5,t-1}\frac{1-\left(\psi_{0,t-1}^{\Delta e}\right)^{j+1}}{1-\psi_{0,t-1}^{\Delta e}} \\
\Omega_{1,t-1}^{j} &= \Omega_{1,t-1}\left(\psi_{1,t-1}^{u}\right)^{j+1} + \Omega_{4,t-1}\Omega_{1,t-1}^{j-1} \\
\Omega_{2,t-1}^{j} &= \Omega_{2,t-1}\left(\psi_{1,t-1}^{\Delta y}\right)^{j+1} + \Omega_{4,t-1}\Omega_{2,t-1}^{j-1} \\
\Omega_{3,t-1}^{j} &= \Omega_{3,t-1}\left(\psi_{1,t-1}^{\pi}\right)^{j+1} + \Omega_{4,t-1}\Omega_{3,t-1}^{j-1} \\
\Omega_{4,t-1}^{j} &= \Omega_{4,t-1}\Omega_{4,t-1}^{j-1} \\
\Omega_{5,t-1}^{j} &= \Omega_{5,t-1}\left(\psi_{1,t-1}^{\Delta e}\right)^{j+1} + \Omega_{4,t-1}\Omega_{5,t-1}^{j-1}
\end{aligned}
$$

with $\Omega^0_{k,t-1} = \Omega_{k,t-1}$, $k = 1, 2, ..., 5$. It is clear from the above expression that the long-term interest rate depends on expectations of several variables, so that policies that focus on a single objective at the cost of others are unlikely to be welfare-enhancing.
Private sector expectations also affect the value of the domestic currency. As there is no well-established specification for the exchange rate equation, only two competing models are considered: the first relates exchange rate dynamics to the ratio of net foreign assets to nominal GDP; the second captures the belief that the value of the domestic currency is a random walk.

$$\begin{aligned} \widehat{E}^{e1}_{t-1} e_t &= e_{t-1} + \beta_{1,t-1} \Delta \tfrac{FA_{t-1}}{Y_{t-1}} + \beta_{2,t-1} \Delta e_{t-1} \\ \widehat{E}^{e2}_{t-1} e_t &= e_{t-1} \end{aligned} \tag{11}$$

Among the set of two-regressor specifications, the model selected (i) minimises the standard error of the regression; (ii) exhibits the second higest correlation with survey measures of exchange rate changes; (iii) has explanatory variables that move closely in line with the first two principal components; (iv) presents the second largest and most stable correlation with the change in the exchange rate. Along with the UIP, equation (11) determines e_t as a function of its own lags, the interest rate differential and foreign indebtedness.

4 Simulation results

Monetary policy rules are ranked on the basis of their impact on social welfare. Society dislikes both price and output variability, defined as the unconditional variances of inflation and GDP growth. The target value of both variables is the steady-state equilibrium value and the two objectives have the same weight in the welfare function, which is equal to:

$$W = -\left[E \left(\pi_t - \overline{\pi} \right)^2 + E \left(\Delta y_t - \overline{\Delta y} \right)^2 \right] \tag{12}$$

Using unconditional variances rather than discounted future losses implicitly favours policies that minimise the overall impact of shocks, penalising those that trade smaller fluctuations today for larger ones tomorrow. Unlike Orphanides and Williams (2007), here the welfare function factors in output rather than unemployment but the change is inconsequential, since in all the experiments the ranking of the policy rules is the same regardless of the argument variable. Interest rate volatility is not included, but it affects social welfare indirectly, since the term structure exerts a powerful influence on GDP.

Model simulations are used to illustrate how the interaction between the expectations formation mechanism and the monetary policy rule affects the equilibrium outcomes. The optimal policy is selected via a grid search on the parameters $\{\rho, \alpha_\pi, \alpha_u\}$ of the Taylor-type reaction function: in order to save on computation time, the step-length of the grid search is initially quite large (.1 for ρ; .5 for α_π and α_u), but gradually diminishes once the region containing the welfare-maximising triplet is located. The search is based on the assumption that ρ ranges between 0 and 1, while α_π and α_u are both positive but cannot be larger than 4. Each experiment consists of 500 replications and all simulations cover an interval of 490 years (from year 2011 to year 2500). In the first 90 periods, the main stochastic equations[25] are shocked to test how effectively the monetary policy rule stabilises the economy;[26] in the subsequent 400 years, all shocks are reset to zero and the model settles down on the steady-state equilibrium growth path, which makes it possible to assess the convergence properties of the learning algorithm. The GSG algorithm is initialised using OLS estimates on historical data.

4.1 Optimal monetary policy under rational expectations

Under rational expectations the optimal monetary policy has a small degree of interest rate smoothing, a strong response to inflation and a non-negligible concern for changes in the unemployment rate (see Fig.1): the welfare-maximising coefficients are $\rho = 0.4$, $\alpha_\pi = 2$ and $\alpha_u = 1.5$.

Comparing the performance of alternative rules provides some notable insights. First, the degree of inertia does not matter greatly: the welfare function is quite flat for positive values of ρ up to 0.7. For higher values, both output and inflation variability increase, suggesting that too smooth a path of the policy interest rate fails to stabilise the economy; for $\rho \geqslant 0.9$ the system no longer converges, showing that difference rules are not a viable alternative. Second, the equilibrium outcomes are not overly sensitive to the value of α_u, possibly because of the role of fiscal policy in stabilising the economy. Close to the local optimum, the welfare function exhibits a hump-shaped response to α_u; away from it, no well-defined relationship is apparent. Third, the policymaker's response to deviations from the inflation target ought to be quite strong: the optimum is achieved when $\alpha_\pi = 2$, while for $\alpha_\pi \leq 1$ the model is not stable, suggesting that the Taylor principle holds. This

[25]The equations are: (i) household consumption, (ii) exports, (iii) the private sector value added deflator and (iv) the consumption deflator. The white-noise shocks may be interpreted as referring to domestic and foreign household preferences and domestic and foreign mark-ups.

[26]To ensure a fair comparison across policy rules, the same sequences of random draws are used for each triplet $\{\rho, \alpha_\pi, \alpha_u\}$.

finding is not trivial, since unlike small closed-economy models with no government, the maquette of the Bank of Italy Quarterly Model model provides for channels other than monetary policy that help to tame inflationary pressures.[27] Social welfare turns out to be very sensitive to changes in α_π, contrary to what happens with α_u or ρ: other things equal, it falls by nearly one sixth when $\alpha_\pi = 3$ and by one third when $\alpha_\pi = 4$. Fourth, mild changes in the weighting of the objectives of the loss function are inconsequential: the optimal policy stays the same when the weight of output stabilisation is halved and remains close to optimal when it is doubled.

4.2 Optimal monetary policy under learning

The foregoing results are based on four partly interrelated hypotheses: (i) the economic environment is *stationary*, since equations do not change over time; (ii) agents know the structure of the economy; (iii) expectations are *rational* and (iv) the central bank is *credibly committed* to an unchanging policy rule. Each assumption has a strong impact on the properties of the system and on the policymaker's incentives and constraints. Uncertainty about the structure of the economy forces policymakers to rely on estimates of the unobserved natural rates; imperfect knowledge on how the economy works alters the way monetary policy and private sector expectations interact; learning makes an otherwise stationary environment non-stationary; and the imperfect credibility of the central bank reduces the authority's ability to steer market expectations.

In order to assess the impact of these assumptions on the central bank's strategy, I run three sets of simulations. In the benchmark case, labelled "no transparency", I assume that agents do not know the current value of the policy interest rate when they take their decisions but observe it with a one-period delay (i.e. the private sector forms expectations before the monetary policy rate for the current period is set). In the second experiment, I assume that the central bank pre-announces the current-period monetary policy stance, so that $\widehat{E}^P_{t-1} i_t = i_t$; this case is dubbed "partial transparency", because the authority communicates neither its own estimates of the natural rates ($\widehat{E}^{CB}_{t-1} r^*_t$ and $\widehat{E}^{CB}_{t-1} u^*_t$) nor the coefficients of the reaction function (ρ, α_π and α_u). The final set of simulations posits a "fully transparent" central bank that provides private agents with all the information it processes in making policy decisions.[28] Comparing the first experiment with the ra-

[27] An increase in inflation worsens price competitiveness and reduces the real value of non-indexed financial wealth; the resulting decline in exports and private-sector spending translates into less employment and decelerating costs. Besides, there is usually fiscal drag weakening aggregate demand. Since these channels are at work in the model, the Taylor principle may not be a necessary condition for determinacy.

[28] The expression "full transparency" is not perfectly appropriate here, as the central bank does not

tional expectations equilibrium, one can assess the welfare losses and the changes of the optimal monetary policy rule due to imperfect knowledge; comparing the other two experiments with the benchmark "no transparency" hypothesis, one can gauge the gains from an effective communication strategy.

The size and complexity of the model make it hard to disentangle the channels through which monetary policy decisions affect the economy and to assess how the parameters of the interest-rate rule bear on output and inflation volatility. In order to determine which factors affect welfare most strongly, social welfare and its drivers have been regressed on the standard deviations of the main macroeconomic variables. Table 1 reports the t-statistics of these regressions: a negative correlation between welfare and the standard deviation of a variable implies that the lower the volatility of that variable, the greater the increase in social welfare. The entries in the table suggest that the anchoring of inflation expectations and the stabilisation of wages and prices are the primary sources of welfare movements: when transparency is not complete, lower variability of surprise and expected inflation results in higher welfare; when transparency is full, wage fluctuations are the main factor in economic instability. The econometric evidence suggests that by controlling nominal variables the monetary policymaker succeeds in keeping the real variables in check as well. The exchange rate and the term spread do not appear to be significant drivers of welfare.

4.2.1 The benchmark case

Table 2a presents summary statistics describing how alternative policy rules work. Monetary policies are appraised according to two indices: the level of welfare and the rejection rate (i.e. the percentage of non-converging replications). Results on the optimal rule are presented in the first row; the other policies are arranged so that only one parameter at a time changes, making it easier to see how sensitive the rule's performance is to changes in each element of the triplet $(\rho, \alpha_\pi, \alpha_u)$. For every combination of parameters, the table shows the first and second moment from steady-state of (i) output, (ii) inflation, (iii) inflation surprises, (iv) private-sector nominal wage growth, (v) the (mean) intercept of the inflation PLMs, (vi) the difference between central bank and private-sector inflation expectations, (vii) the optimal capital-output ratio, (viii) the short and (ix) the long-term interest rate. In the last two columns, the table shows the entropy of inflation and of the policy rate, measuring the uncertainty agents face in choosing the forecasting model.

communicate everything to the public, e.g. its PLM for inflation and the variables entering the interest-rate rule.

The entropy H of a discrete random variable X, whose values are $\{x_1, x_2, ..., x_K\}$, is defined as $H(X) = -\sum_{k=1}^{K} p(x_k) \log_b p(x_k)$, where $p(x_k)$ is the probability of drawing x_k and b is the base of the logarithm. $H(X)$ reaches its maximum when, for each x_k, $p(x_k) = 1/K$ and its minimum when $p(x_k) = 1$ for one x_k and zero otherwise. Common values for b are $2, e$ or 10; alternatively, one can choose $b = K$ so that $H(X) \in [0, 1]$. In this paper, x_k represents the k^{th} forecasting model and $p(x_k)$ is the share of agents buying its predictions; $H(X) = 1$ means that the data do not help to discriminate among models, while $H(X) = 0$ indicates that one predictor dominates and precludes the others. Comparing the equilibrium outcomes under rational expectations and learning, it seems that neither the uncertainty about the natural rate nor the expectations formation mechanism entail substantial welfare losses: the optimal policy under learning achieves nearly the same welfare level as the optimal policy under rational expectations, and even suboptimal ones perform quite well in most cases. What does change is the shape of the optimal policy rule: under adaptive learning, the optimal policy requires a weaker response to deviations of inflation from target ($\alpha_\pi = 0.4$ rather than $\alpha_\pi = 2.0$) and a stronger concern for output stabilisation ($\alpha_u = 3.5$ rather than $\alpha_u = 1.5$). This outcome depends mostly on the exchange rate: under adaptive learning, exchange rate expectations are stickier and the value of the currency - and hence inflation - is less volatile, which induces the monetary policymaker to pay more attention to output stabilisation. The degree of inertia is roughly the same ($\rho = 0.3$ rather than $\rho = 0.4$), but it does not seem to play a substantial role: social welfare is to a large extent unaffected by the coefficient of the lagged interest rate and does not change significantly for values of ρ in the range $[0.3, 0.5]$; as ρ increases, output fluctuates less and inflation more.

Concerning the performance of alternative monetary policy rules under learning, table 2a offers several insights. In particular, it shows that inflation volatility is much more responsive than output volatility to changes in ρ, α_π and α_u: the range of variation of the standard deviation of inflation is about seven times that of output. Not surprisingly, the best-performing rules are those that anchor prices better, even if this comes at the cost of wider fluctuations in the level of economic activity. If the inertia of the policy rule decreases from 0.8 to 0.3, inflation volatility decreases by one-fourth, while that of output increases by less than one-fiftieth; if α_π falls from 2.5 to 0.5, the second moment of both of the central bank's objectives diminishes; if α_u rises from 1.0 to 2.5, inflation counterintuitively becomes much less erratic and output fluctuates more. More effective rules have a low or even zero rejection rate; moreover, the share of non-converging replications seems to be proportional to the degree of inertia and inversely related to responsiveness to the unemployment gap.

The best-performing policies are therefore those that (1) have low inertia; (2) do not overreact to changes in inflation; and (3) lean strongly against aggregate demand shocks. These rules succeed in keeping price fluctuations under control mostly through expectations management. Applying the law of total variance, the second moment of inflation (i.e. $Var(\pi_t)$) can be decomposed into the sum of the expected value of its conditional variance ($E(Var(\pi_t|I_{t-1}))$) and the variance of its conditional expectation ($Var(E(\pi_t|I_{t-1}))$): the first term can be proxied by the variance of time-t inflation surprises averaged across time, the second by the variance of expected inflation, where expected inflation in each period is computed averaging across replications. The recipe for effectiveness is therefore to make inflation predictable (which reduces the first term) and to prevent expectations from decoupling from targets (which minimises the second).[29] If these two requirements are not met, wages - which depend on inflation expectations - become excessively erratic and nominal instability is transmitted to households' and firms' spending decisions. Table 2a confirms that a high level of welfare is in general associated with predictable inflation and stable expectations: predictability is inversely related to the volatility of inflation surprises.

Expectations are one of the key elements in understanding how the economy responds to monetary policy actions. If beliefs are not homogeneous, a natural question is whether model heterogeneity disappears as data accumulates: the answer is a resounding no, regardless of the central bank's communication strategy.

With regard to short-term interest-rate expectations, the two PLMs that include output growth and next-period inflation (the 4^{th} and 6^{th} models) outperform the others, despite the fact that the central bank policy rule uses the unemployment rate as a proxy for slackness in economic activity. The population state gradually converges towards a situation where more than 80% of the agents use one of these two models. Similar results are found for expected inflation. The best-fitting PLM has unit labour costs and the import deflator as regressors, while the second-best has the unemployment rate as the sole explanatory variable; taken together, they account for nearly 85% of agents' picks. The ranking of the forecasting models is more or less the same across replications and end-of-sample proportions cluster together quite neatly. For the exchange rate the picture is different: neither of the two forecasting models clearly stands out and the relative accuracy of the competing PLMs seems to be driven by a combination of shocks to the economy. Unlike

[29] The alignment between target and expected inflation is also measured by the first and second moments of the intercept of the forecasting models used for predicting inflation. Both statistics are shown in table 1.

the other variables, exchange rate expectations are highly dispersed across replications. One finding is common to all three cases and to all transparency regimes: highly inaccurate forecasting models tend to be discarded, but no PLM succeeds in ruling out all the others, possibly because there is not enough information in the data. Heterogeneity in expectations formation seems to be an intrinsic feature of the model: even for the policy interest rate - which depends on a small set of variables and is more accurately tracked by agents' expectations - two PLMs coexist. Does this finding depend on the value of the sensitivity parameter λ of the payoff function? Not really. Fig. 2 shows that even for very high values of the responsiveness of the payoff function to forecast errors, the heterogeneity in expectations formation does not disappear. On the contrary, excessively high values of λ tend to reduce the share of agents choosing the two best forecasting models, especially for inflation: heterogeneity in expectations stops decreasing, and the selection of forecasting models becomes more and more erratic. Indeed, when λ exceeds a certain threshold (i.e. when $\lambda \geqslant 2500$) social welfare deteriorates: the volatilities of output growth and inflation increase, as agents tend to switch too frequently from one forecasting model to another, making predictions inaccurate and disanchoring expectations.

These results clash with those of Orphanides and Williams (2007), who find that when private agents have imperfect knowledge, the central bank benefits from more strongly inflation-averse policies, which help prevent expectations from decoupling from target inflation. This contrasting evidence is explained by differing monetary policy transmission mechanisms. The Orphanides-Williams model is a plain-vanilla three-equation New-Keynesian model: the policy instrument affects aggregate demand directly and inflation indirectly (through the output gap); as long as interest rate changes offset inflationary pressures, they stabilise the economy and have negligible spillovers on social welfare.[30] The model used in this paper has a much richer transmission mechanism, where expectations not only drive monetary policy choices but also affect wage setting, competitiveness and asset prices: a strong interest-rate response to price shocks makes actual inflation more erratic and less predictable. What happens is that by overreacting to inflationary pressures, the policymaker induces greater fluctuations in consumption and investment, putting additional pressures on prices. The net effect is to amplify rather than attenuate the initial shock.

An additional channel affecting the transmission of monetary impulses works through asset prices. A tightening of the policy stance results in an appreciation of the currency, which keeps price dynamics in check, both directly (through a lower import deflator) and

[30]Provided of course that interest rate volatility does not have a large weight in the loss function.

indirectly (through the impact of a deterioration in price competitiveness on economic activity). But the simulation results suggest that this channel plays only a minor role in shaping the response of the economy to monetary impulses. Policy stimuli bear upon the yields of long-term bonds and the slope of the term structure of interest rates also. There is no easily discernible relationship among the coefficients of the policy rule, the volatility of the term structure and social welfare. Considering the volatility of inflation-adjusted yields, it clearly has a positive effects on the standard deviation of output growth, but the impact on welfare is distorted by the response of inflation, whose fluctuations seem to be dampened by more volatile real interest rates.[31]

Two other findings are worth mentioning. First, the Taylor principle does not apply: though the welfare-maximising value of α_π is 0.4, the model is stable and learnable, and the rejection rate is zero.[32] Second, the optimal rule has the lowest entropy associated with the predictor proportions of PLMs for the short-term interest rate, suggesting that one ingredient in a successful policy is enabling agents to discriminate between good and bad forecasting models.

4.2.2 The case of partial transparency

Transparency of monetary policy refers to the absence of information asymmetries between policymakers and the private sector. Perfect transparency, in the setup used here, implies that the central bank discloses to the general public both its estimates of the natural rates and the precise form of the policy rule; incomplete transparency is defined as a situation where the policymaker communicates in advance only the monetary stance (i.e. the value of i_t). In this case, expectations about future policy rates, which are needed to price long-term securities, are formed with a PLM that differs from the true interest-rate rule, namely:

$$\begin{aligned}\widehat{E}^i_{t-1} i_{t+j} &= \Omega^j_{0,t-1} + \Omega^j_{1,t-1} u_{t-1} + \Omega^j_{2,t-1} \Delta y_{t-1} \\ &+ \Omega^j_{3,t-1} \pi_{t-1} + \Omega^{j-1}_{4,t-1} i_t + \Omega^j_{5,t-1} \Delta e_{t-1}\end{aligned}$$

Table 2b shows the results of the simulations under partial transparency. There seems

[31] The link between learning and interest rates is not a novel feature of this paper. Dewachter and Lyrio (2006) present a macroeconomic model in which agents learn about the central bank's inflation target and the real interest rate to explain the joint dynamics of output, inflation and the term structure of interest rates. Learning generates endogenous stochastic endpoints that act as level factors for the yield curve. They find that their model has a better fit than those based on rational expectations and generates sufficiently volatile endpoints to match the variation in long-maturity yields and in surveys of inflation expectations.

[32] Svensson (2000) explains why the Taylor principle does not hold in open economies.

to be only a modest gain from being transparent: the optimal policy achieves a level of welfare that is just slightly better than the best outcome under opaqueness. Some benefits are discernible in lower rejection rates and in the way the central bank manages to steer agents' behaviour: when agents know in advance what the central bank is going to do, they behave in a way that is consistent with the monetary stance, fostering the achievement of the objectives with smaller changes in the policy instrument. Less volatile short-term interest rates promote a somewhat flatter term structure and are conducive to a more precise appraisal of the unobserved natural rates, though the evidence is not unambiguous.

4.2.3 The case of full transparency

The equilibrium outcomes change substantially when the central bank is fully transparent and discloses all the information that it uses in choosing its monetary stance. Full trasparency holds when no information asymmetry between the central bank and the general public exists. Since the central bank informs market participants of the coefficients of the policy rule, the inflation objective, and its own estimates of the natural rates, expectations about future policy rates are set according to the following equation:

$$\begin{cases} \widehat{E}^i_{t-1} i_{t+j} & = & \rho \widehat{E}^i_{t-1} i_{t-1+j} + (1-\rho)\, i^*_{t+j} \\ i^*_{t+j} & = & \widehat{E}^{CB}_{t-1} r^*_t + \overline{\pi} + \alpha_\pi \left(\widehat{E}^i_{t-1} \pi_{t+1+j} - \overline{\pi} \right) - \alpha_u \left(\widehat{E}^i_{t-1} u_{t+j} - \widehat{E}^{CB}_{t-1} u^*_t \right) \end{cases}$$

for $j > 0$. The only remaining information asymmetry is the one about the PLMs for inflation and the unemployment rate, which are not the same for the central bank and the private sector. As shown in Table 2c, the best performing rule features a much higher degree of inertia, a stronger inflation aversion and a lower concern for output fluctuations. The sensitivity to changes in the value of ρ is high: for $\rho = .3$, welfare is nearly 20 p.p. lower than at the optimum. A low degree of inertia tends to destabilise the exchange rate and raises substantially the cost of financing, which justifies the deterioration of the policy performance.[33] Welfare is also sensitive to the value of α_u, since too weak a response to unemployment gaps injects variability in inflation. It is worth stressing that though the optimal strategy exhibits a larger α_π and a smaller α_u than in the partial and no-transparency cases, output fluctuates less and inflation more; moreover, for most combinations of $\{\rho, \alpha_\pi, \alpha_u\}$, the policy interest rate tends to be less volatile, but the long-term yield exhibits much larger fluctuations. A possible explanation is that when the natural

[33] As shown in Table 2c, the bias of the long-term interest rate - i.e. the difference between the mean value across time and replications and the steady-state value - is always larger than 200 basis points.

rates and the policy parameters are not estimated, but provided by the central bank, there is no automatic error-correction mechanism working through recursive learning, so that expected future policy rates become extremely erratic and the term structure biased and volatile.[34]

One noteworthy feature is that in all cases, even when the overall performance of the policy rule is poor, the standard deviation of output is smaller than under partial transparency or opaqueness.[35] Higher inflation volatility is traded for lower output volatility, as witnessed also by the standard deviation of the capital-output ratio, which is substantially smaller than in the other two cases. Notwithstanding the relatively large variability of inflation, the mean intercept of the inflation PLMs turns out to be mush less biased and unstable. While the optimal rule does not improve significantly upon the partial and no-transparency case, suboptimal strategies seems on average to perform better, suggesting that transparency may be conducive to robustness. All in all, it seems that central bank talk has a beneficial but very modest impact on agents' expectations and behaviour. The explanation of this finding echoes the warning of Amato, Morris and Shin (2002), who note that central bank communication has a dual function: on the on hand, it provides signals about the policymaker's private information; on the other hand, it serves as a coordination device for the beliefs of private agents and may at times induce agents to do away with their own private information. The first effect is welfare-enhancing; the second may be welfare-reducing. Which effect prevails cannot be said in general: in the case considered, it seems that the benefits of adopting a completely transparent policy are largely offset by its shortcomings.

4.3 Perpetual learning

The canonical justification for adopting gain sequences that remain bounded above zero is that the economy is subject to structural shifts and, accordingly, past observations should be given less weight than recent data in the learning algorithm. There is actually a second rationale for using constant-gain estimators that fits the model in this paper perfectly:

[34] This guess is confirmed by the value - not reported in the table - of the 1^{st} and 2^{nd} moments of the variable measuring interest-rate missperceptions, i.e. $\frac{1}{6}\sum_{j=1}^{6}\left(i_{t-1}-\widehat{E}_{t-1-j}i_{t-1}\right)$, which are much larger than in the previous cases.

[35] It is not certain however that this outcome is to be attributed to monetary policy. An alternative possibility is that this result is due to fiscal policy: at the optimum point, the standard deviation of the tax rate on disposable income (which is the fiscal policy instrument used to keep the debt-to-GDP ratio close to its target of 0.6) is more volatile and much higher than in the steady-state equilibrium; in the partial and no-transparency cases, the opposite happens.

the possibility of nonconvergence to the REE. If convergence to the perfect information equilibrium is for whatsoever reason unlikely, then the actual stochastic process followed by the economy may best be modelled - given the PLMs employed by agents - as undergoing structural change over time. The main implication of constant-gain learning is that agents' estimates are always subject to sampling variation and never converge to fixed values; for this reason, some authors name this adaptive scheme "perpetual learning".

Table 3a to 3c report the simulation results under the three alternative communication strategies in the case of perpetual learning. Under no trasparency, there is hardly any difference between the decreasing and constant gain cases.

The best policy is essentially the same, just a bit more inertial ($\rho = .31$ rather than $\rho = .3$) and slightly less reactive to fluctuations in real activity ($\alpha_u = 3.2$ rather than $\alpha_u = 3.5$). Welfare is apparently not affected by the memory of the learning algorithm: it is either the same or slightly lower, suggesting that observations far away in the past are indeed barely informative. The ranking of suboptimal policies is not altered either: the worst outcomes are achieved when either α_π is too high or α_u is too low.

Similar results are obtained when the central bank discloses the information it uses in making policy decisions. Under partial transparency, the welfare-maximising policy features a slightly milder response to the unemployment gap ($\alpha_u = 3$ vs. $\alpha_u = 3.2$). Under full transparency the opposite happens: the optimum is achieved with a somwhat higher value of α_u and a somewhat lower value of α_π. In general, the simulations confirm that when the monetary policymaker reacts too aggressively to price shocks or too meekly to demand fluctuations, the economy becomes unstable and social welfare plunges.

5 Sensitivity analysis

The results just described are based on several ad-hoc assumptions. On some of them - the number of replications in each experiment or the initial conditions of the learning process - a thorough sensitivity analysis can be conducted; on others - the choice of the PLMs - no fully-satisfactory testing procedure is available: with hundreds of variables, there are too many PLMs that can be chosen, most of them indistinguishable in terms of parsimony or fitting.

To test the generality of the findings described in the previous section, four sensitivity analysis exercises are conducted: in the first, the model is simulated with 10,000 replications and the results compared with those obtained in the baseline experiment, to test whether the latter are distorted by the small number of replications; in the second, the initial conditions of the learning algorithm are changed, by increasing/decreasing the (fixed) covariance matrix of the regressors, that drives the size of the Kalman gain and accordingly the extent of the revisions in expectations once new data becomes available; in the third, the sensitivity of the optimal monetary policy rule to changes in the welfare function is assessed; in the final experiment, initial conditions for predictor proportions x_t^i are set randomly, by drawing from a uniform distribution with support in $[0, 1]$, instead of imposing that they are equal to the reciprocal of the number of forecasting models and constant across replications.

5.1 Experiment #1: the number of replications

For each experiment, the number of replications has been chosen so as to guarantee reliable results while keeping the time needed for a full search of the optimal policy at an acceptable level. The model, augmented with the learning recursions, contains nearly 300 equations: when all 500 replications converge, it takes roughly two minutes to complete them; when some of them diverge, it can require two hours of computer time. Since the search for the optimum policy calls for the evaluation of more than 300 combinations of the Taylor-rule coefficients, 500 replications has been viewed as an acceptable compromise. To assess whether the results shown in Tables 2a to 2c are affected by small sample bias, the equilibrium outcomes of the three communication regimes at the optimum have been compared with the results obtained by running 10,000 replications. Table 4 presents a summary of the findings. Only three variables are compared: social welfare, output growth and inflation; for the latter two, both the first (bias) and the second moment (volatility) from the steady-state equilibrium are considered. Each entry is the ratio between the value computed in 10,000 replications and that obtained in 500 ones; for all ratios, the mean, the median, the maximum and the minimum across replications are shown.

According to the evidence presented in Table 4, the size of the small sample bias is negligible: regardless of the transparency regime, the difference in welfare does not reach 2 percentage points and the discrepancy is even smaller for the volatility of output growth and inflation. The estimates of the biases are less alike and sometimes even change sign, but this is no evidence of the existence of a significant small-sample bias: both the numerator and the denominator of the ratios are close to zero, so that even small differences can lead to high jumps in the ratio. The precision of the estimates based on few replications is confirmed by looking at the ratios between the maxima and minima, which are surprisingly low.

5.2 Experiment #2: the size of Γ

A second type of sensitivity analysis has been conducted on initial conditions of the learning algorithm. A critical parameter is Γ, the moment matrix of the regressors entering the (generalised) stochastic gradient learning recursive equations: unlike the coefficients of the PLM, the matrix Γ is not updated, but held fixed at some assigned level. To assess the influence of the value of Γ on the ranking of the policy rules, other simulations have been run, using $k\Gamma$ as the moment matrix of the regressors. Six cases have been considered, corresponding to $k = \left\{\frac{9}{10}, \frac{11}{10}, \frac{3}{4}, \frac{5}{4}, \frac{1}{2}, \frac{3}{2}\right\}$. Table 5 shows the results for the three monetary regimes and the 6 values of k; the entries in the table indicate the rank of each policy rule in terms of social welfare. In the final two rows, the Spearman ρ and the Kendall τ rank correlation coefficients are presented.

The results are reassuring. In the full transparency case, there is no uncertainty about which is the welfare-maximising policy rule: all values of $k\Gamma$ point to the same rule. Something similar happens in the partial transparency case, where the optimal policy is identified for all values of k except $\frac{3}{2}$, while the ranking in the no-transparency regime seems to be somewhat more dependent on choice of Γ. The sample values of the rank correlation coefficients - surprisingly high in nearly all cases - confirm that the actual value of Γ is quite irrelevant not only in detecting the optimal policy, but also in ordering suboptimal ones.

5.3 Experiment #3: specification of the welfare function

The welfare function (12) used in the paper does not penalise interest rate instability and attributes the same importance to the volatility of inflation and that of output growth. The first feature is justified on the grounds that in a sufficiently large model excess volatility of the monetary policy instrument trasmits to other asset prices, affecting private-sector spending decisions, so that it is implicitly incorporated in the volatility of output and inflation; the second feature reflects the desire to treat evenly fluctuations in nominal and real variables, as in Orphanides and Williams (2007).

As it is unclear which are the appropriate weights of the different arguments of the welfare functions, it is advisable to test how sensitive is the choice of the best-performing monetary policy rule to the specification of social preferences. A more general specification of the welfare function is

$$W = -\left[\zeta E\left(\pi_t - \overline{\pi}\right)^2 + (1-\zeta)\, E\left(\Delta y_t - \overline{\Delta y}\right)^2 + \omega E\left(i_t - \bar{i}\right)^2\right] \tag{13}$$

The parameter ζ measures the degree of inflation aversion, while non-zero values of ω signal that society dislikes interest rate volatility as well. For $\zeta = .5$ and $\omega = 0$, (13) coincides with (12); $\zeta = .5$ and $\omega = 0.125$ are instead the values used in Orphanides and Williams (2007).

Tables 6a to 6c show how different combinations of the parameters (ζ, ω) affect the ranking of monetary policy rules. Each row of the table corresponds to a policy rule, while the columns refer to alternative values of the weights of the interest rate and inflation objectives relative to that of output growth. In the last two rows of the table, the Spearman's and Kendall's rank correlation coefficients are shown.

Three findings are worth stressing: (1) save the case when the degree of inflation aversion of the monetary policymaker is very low, changes in the weight of the inflation objective have no impact on the choice of the best-performing rule: the rank correlation coefficients is in all but one case not just high, but equal to 1; (2) adding interest rate volatility to the welfare function does not influence the ordering of the policy rules, unless its weight is unreasonably high. Using the same specification as in Orphanides and Williams (2007), does not alter the results shown in table 2a to 2c; (3) in the full transparency case, the ranking of the policy rules turns out to be much more sensitive to the inclusion of interest rate volatility in the welfare function, though the main features of the best-performing policy changes only marginally. In general, more inertial and less activist policies seem to becomes more effective. The main rationale of this outcome is that under full transparency the short-term interest rate is much more volatile than inflation and output growth, so that even for low values of ω the shape of the welfare function changes in a non-negligible way.

5.4 Experiment #4: stochastic initial conditions for model proportions x_t^i

In all the experiments described so far, initial conditions for predictor proportions x_t^i are set equal to the reciprocal of the number of models used to forecast a given variable and are kept constant across PLMs and replications, under the presumption that this creates a level playing field for all competing forecasting models. To assess whether this assumption does indeed leave the model selection process unaffected, additional simulations are run, this time drawing initial conditions from a uniform distribution with support in (a finite subset of) $\mathbb{R}^+$; the constraints on model proportions are enforced by rescaling each draw so as to ensure a unit sum. Table 7 shows predictor proportions at the end of the simulation horizon under fixed and random initial conditions, together with two other statistics: the standardised difference between average predictor proportions and the correlation between initial conditions and limit values of model shares.

For all the variables - short-term interest rata, inflation and exchange rate - the table clearly shows that initial conditions do not matter much: the ranking of the models is the same regardless of the way initial conditions are set and the standardised difference between predictor proportions is always well below one and quite close to zero. The correlation between initial and final values of the predictor proportions is in general non-negligible, suggesting that initial conditions are not irrelevant, though not important enough to change the long-run behaviour of the system.

6 Conclusions

This paper has analysed the properties of a large non-linear model populated by boundedly rational and incompletely informed agents. When the economy is sufficiently complex, individuals do not know the "true" law of motion of the variables they need to predict and are confronted with a host of equally plausible forecasting models. If agents can pick one out of a large number of predictors, none of which clearly superior, there is no guarantee that everyone selects the same one; in addition, they may choose to change to a different forecasting model if the predictive accuracy of the one that they are using deteriorates. Expectations therefore end up being misspecified, heterogeneous and ever-changing, even asymptotically, when enough observations are available to detect which forecasting model exhibits the best predictive performance. As the equilibrium to which the economy asymptotically converges differs from the REE and depends on the specific form of the expectations equations, central bank communication may be beneficial if it helps private agents to coordinate their beliefs. The paper is an attempt to assess whether in such a model economy the implications for monetary policymaking are similar to those found in the literature for small, linear systems and whether higher degrees of transparency are welfare-enhancing. The main findings are the following. First, expectations heterogeneity is an intrinsic feature of the economy: regardless of the monetary policy in place, no PLM succeeds in ruling out all the other forecasting models, though the most inaccurate ones are eventually dismissed. Second, the monetary policymaker has much weaker incentives (than, e.g., in the paper by Orphanides and Wiliams) to adopt more inflation-averse policies, since too strong a reaction to price shocks increases both inflation and output volatility and tends to make the model unstable and non-learnable. At first sight, this outcome seems quite counterintuitive: a central bank that is committed to tame inflationary pressures is presumably more credible and more effective in anchoring long-run inflation expectations and bond yields. This connection however is not present in the model and credibility depends on outcomes, not intentions: agents learn from the data and what matters is whether monetary policy makes the economy more stable. Third, more transparent policies are in some cases mildly welfare-enhancing, but they never warrant sizeable improvements; the degree of transparency alters the form of the optimal policy rule also, as it increases inflation aversion. Disclosing more information is however not always beneficial.

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Fig.1 − Social welfare under rational expectations

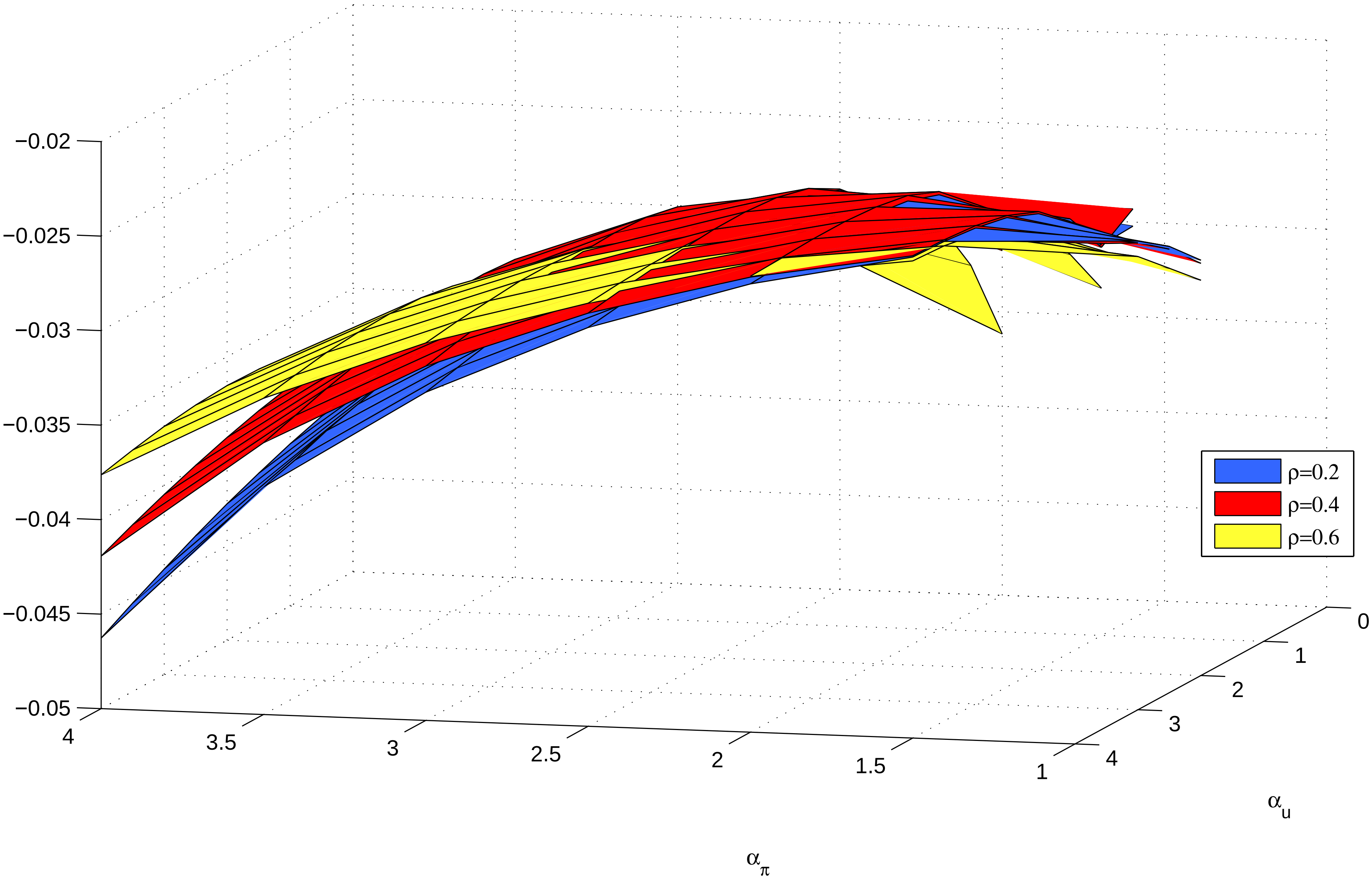
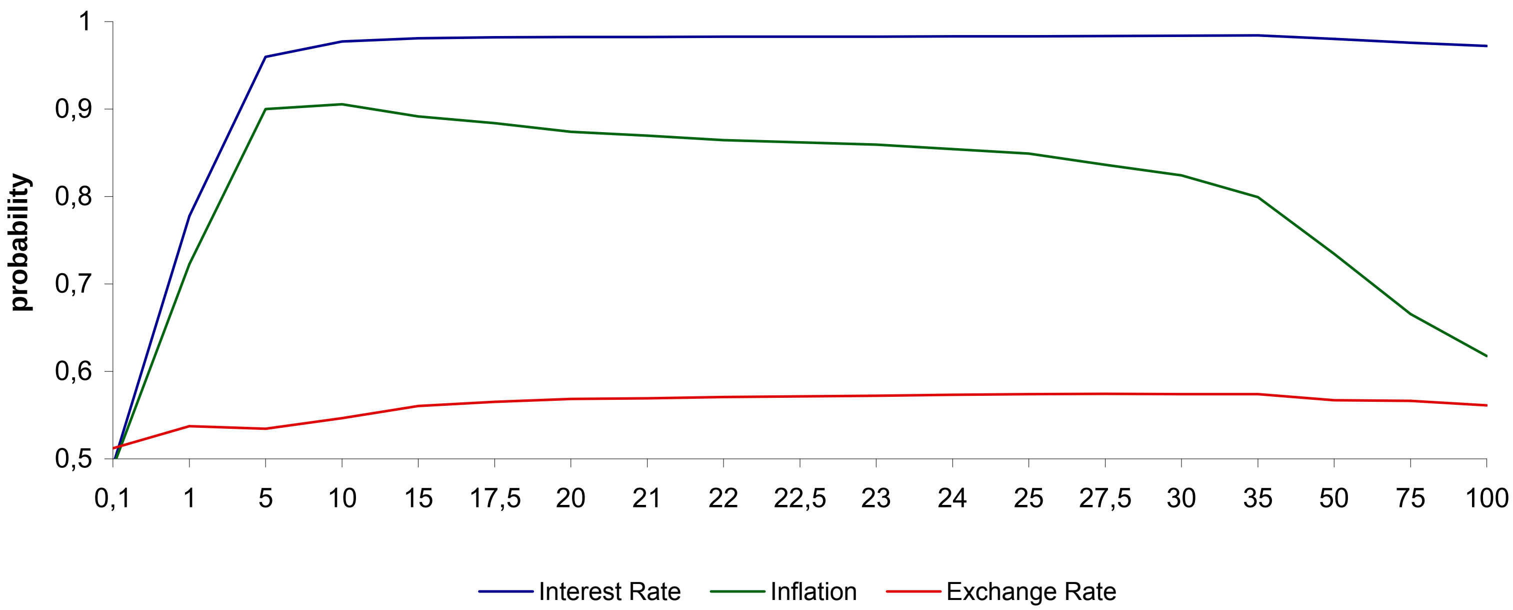


Fig.2 - Predictor proportions and payoff function



Note: The values reported on the x-axis are scaled by 1000, implying that the value *λ=1000* used in the simulations corresponds to the value of 1 on the x-axis. The blue and green lines represent the sum of the predictor proportions of the two most successful forecasting models for the short-term interest rate and for inflation; the red line shows the share of agents adopting the best predictive model for the exchange rate.

Table 1 - Impact on welfare of the volatility of the main macroeconomic variables

The table reports the *t*-statistic of the simple regression of welfare and the standard deviation of the arguments of the welfare function on the volatility of a subset of the main macroeconomic variables included in the model. The first column lists the set of regressors; the subsequent ones, coming in groups of three (one group for each transparency regime), show the *t*-statistic of the regression of, respectively, welfare, the volatility of output growth ($\sigma_{\Delta y}$) and the volatility of inflation (σ_{π}) on the variable indicated in the first column. The notation is used as follows: π^e is expected inflation; $\pi-\pi^e$ is surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; k^* is the optimal capital-output ratio; $\Delta\pi^e$ is the difference between central bank and private-sector inflation expectations; i and i^L are the short (policy) and long-term interest rate; $i-\pi$ and $i^L-\pi$ are the corresponding real rates; $i-i^L$ is the term spread; e is the exchange rate.

	No Transparency			**Partial Transparency**			**Full Transparency**		
volatility of:	*Welfare*	$\sigma_{\Delta y}$	σ_{π}	*Welfare*	$\sigma_{\Delta y}$	σ_{π}	*Welfare*	$\sigma_{\Delta y}$	σ_{π}
π^e	-34,19	-4,52	71,86	-37,97	-5,55	68,02	-5,53	-8,05	7,38
$\pi-\pi^e$	-35,57	-4,53	193,68	-42,04	-5,54	180,24	-35,59	-5,15	42,75
Δw	-21,87	-5,12	37,32	-21,89	-6,23	33,43	-41,33	-4,23	19,24
Θ_0	-17,28	-5,40	26,67	-21,65	-6,24	31,79	0,09	1,24	-0,44
k^*	-1,03	-0,97	1,12	-0,12	-0,27	0,15	-4,19	-1,28	3,32
$\Delta\pi^e$	1,72	3,30	-1,88	1,50	2,52	-1,64	-6,39	-9,53	8,38
i	-0,03	0,63	-0,15	0,07	0,57	-0,17	-0,67	-1,89	1,04
i^L	0,20	0,76	-0,39	0,23	0,60	-0,32	0,19	-1,21	0,18
$i^L-\pi$	3,67	8,45	-4,38	3,37	5,21	-3,75	0,27	-1,15	0,11
$i-\pi$	1,29	1,93	-1,53	1,45	1,96	-1,59	-0,33	-1,75	0,72
i^L-i	0,10	0,84	-0,30	0,33	0,90	-0,45	0,47	-0,81	-0,11
e	-0,85	-1,00	0,95	-0,11	-0,31	0,14	0,53	-0,94	-0,14

Table 2a - Monetary policy effectiveness under no transparency

(decreasing gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and $\pi\text{-}\pi^e$ are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; k^* is the optimal capital-output ratio; i and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

ρ	α_π	α_u		W	RR	Δy	π	$\pi\text{-}\pi^e$	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.3	α_π=0.4	α_u=3.5	vol.	-0,026	0,0	1,115	1,137	1,076	1,15	1,90	0,15	3,22	1,905	0,543	0,061	0,024
			bias			0,005	0,057	-0,003	0,06	1,89	-0,13	3,22	0,589	0,012	0,786	0,641
ρ=0.8			vol.	0,711	22,0	1,043	1,546	1,29	2,15	3,11	0,14	3,23	1,834	0,518	0,08	0,021
			bias			0,004	0,064	-0,01	0,07	2,96	-0,11	3,23	0,509	-0,053	0,71	0,744
ρ=0.6			vol.	0,852	0,8	1,052	1,340	1,18	1,68	2,53	0,14	3,22	1,763	0,492	0,07	0,022
			bias			0,003	0,058	-0,01	0,06	2,45	-0,11	3,22	0,652	0,026	0,75	0,720
ρ=0.5	α_π=1.0	α_u=2.0	vol.	0,890	0,4	1,057	1,297	1,16	1,58	2,40	0,14	3,22	1,730	0,478	0,07	0,020
			bias			0,003	0,056	-0,01	0,06	2,34	-0,12	3,22	0,673	0,045	0,76	0,714
ρ=0.4			vol.	0,912	0,4	1,060	1,273	1,15	1,52	2,32	0,14	3,22	1,712	0,470	0,07	0,021
			bias			0,003	0,056	-0,01	0,06	2,27	-0,12	3,22	0,688	0,058	0,76	0,709
ρ=0.3			vol.	0,922	0,4	1,063	1,260	1,14	1,48	2,27	0,14	3,22	1,704	0,466	0,07	0,022
			bias			0,003	0,055	-0,01	0,06	2,23	-0,12	3,21	0,699	0,069	0,76	0,706
	α_π=0.5		vol.	0,814	4,4	1,046	1,394	1,21	1,80	2,75	0,14	3,24	1,623	0,481	0,08	0,021
			bias			0,004	0,073	-0,01	0,08	2,65	-0,11	3,23	0,400	-0,080	0,74	0,713
	α_π=1.0		vol.	0,804	4,0	1,047	1,405	1,22	1,83	2,78	0,14	3,23	1,795	0,505	0,08	0,023
			bias			0,003	0,060	-0,01	0,06	2,68	-0,11	3,22	0,608	-0,004	0,73	0,729
ρ=0.7	α_π=1.5	α_u=2.0	vol.	0,787	3,2	1,049	1,424	1,23	1,88	2,80	0,13	3,22	1,988	0,551	0,08	0,027
			bias			0,003	0,050	-0,01	0,05	2,70	-0,11	3,21	0,796	0,062	0,73	0,743
	α_π=2.0		vol.	0,750	1,6	1,052	1,460	1,25	1,97	2,82	0,13	3,21	2,215	0,617	0,08	0,034
			bias			0,002	0,044	-0,01	0,05	2,71	-0,10	3,21	0,971	0,116	0,73	0,752
	α_π=2.5		vol.	0,764	1,6	1,055	1,453	1,24	1,97	2,82	0,13	3,20	2,379	0,662	0,08	0,039
			bias			0,002	0,037	-0,01	0,04	2,71	-0,10	3,20	1,114	0,166	0,72	0,754
ρ=0.7	α_π=1.0	α_u=1.0	vol.	0,684	55,6	1,040	1,607	1,32	2,24	3,18	0,14	3,23	1,436	0,367	0,08	0,020
			bias			-0,002	0,082	-0,03	0,09	3,02	-0,11	3,23	0,554	0,009	0,70	0,749
		α_u=1.5	vol.	0,711	16,0	1,041	1,546	1,29	2,11	3,06	0,14	3,23	1,712	0,472	0,08	0,021
			bias			0,002	0,072	-0,02	0,08	2,92	-0,11	3,23	0,561	-0,011	0,71	0,739
		α_u=2.0	vol.	0,804	4,0	1,047	1,405	1,22	1,83	2,78	0,14	3,23	1,795	0,505	0,08	0,023
			bias			0,003	0,060	-0,01	0,06	2,68	-0,11	3,22	0,608	-0,004	0,73	0,729
		α_u=2.5	vol.	0,863	0,0	1,057	1,320	1,17	1,66	2,49	0,14	3,22	1,887	0,536	0,07	0,024
			bias			0,004	0,056	-0,01	0,06	2,42	-0,11	3,22	0,657	0,006	0,76	0,723

Table 2b - Monetary policy effectiveness with transparency

(decreasing gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and $\pi\text{-}\pi^e$ are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; k^* is the optimal capital-output ratio; i and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

				W	RR	Δy	π	$\pi\text{-}\pi^e$	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.26	α_π=0.7	α_u=3.2	vol.	-0,025	0,0	1,106	1,118	1,064	1,129	1,910	0,148	3,219	1,781	0,543	0,057	0,025
			bias			0,005	0,057	-0,005	0,057	1,900	-0,126	3,217	0,616	0,045	0,797	0,649
ρ=0.8			vol.	0,730	17,2	1,041	1,490	1,260	2,041	2,950	0,137	3,225	1,737	0,525	0,075	0,023
			bias			0,003	0,060	-0,015	0,064	2,820	-0,108	3,222	0,489	0,023	0,726	0,757
ρ=0.6			vol.	0,878	0,4	1,051	1,288	1,154	1,580	2,410	0,137	3,217	1,656	0,507	0,067	0,021
			bias			0,003	0,057	-0,011	0,059	2,350	-0,115	3,214	0,621	0,076	0,766	0,729
ρ=0.5	α_π=1.0	α_u=2.0	vol.	0,902	0,0	1,056	1,257	1,137	1,498	2,310	0,138	3,215	1,638	0,502	0,064	0,022
			bias			0,003	0,058	-0,012	0,061	2,250	-0,117	3,213	0,647	0,092	0,773	0,720
ρ=0.4			vol.	0,923	0,0	1,059	1,235	1,125	1,442	2,240	0,139	3,213	1,624	0,499	0,062	0,024
			bias			0,003	0,057	-0,012	0,059	2,200	-0,119	3,211	0,661	0,105	0,777	0,714
ρ=0.3			vol.	0,933	0,0	1,062	1,224	1,119	1,408	2,200	0,139	3,211	1,618	0,500	0,061	0,026
			bias			0,003	0,056	-0,013	0,058	2,160	-0,120	3,209	0,672	0,119	0,778	0,711
	α_π=0.5		vol.	0,824	2,4	1,047	1,350	1,185	1,714	2,610	0,140	3,233	1,539	0,496	0,071	0,023
			bias			0,004	0,074	-0,013	0,079	2,520	-0,114	3,230	0,387	-0,042	0,752	0,721
	α_π=1.0		vol.	0,829	2,8	1,046	1,351	1,186	1,729	2,630	0,137	3,220	1,690	0,516	0,073	0,022
			bias			0,003	0,058	-0,012	0,061	2,540	-0,112	3,217	0,581	0,056	0,748	0,741
ρ=0.7	α_π=1.5	α_u=2.0	vol.	0,802	2,0	1,047	1,376	1,201	1,791	2,660	0,134	3,208	1,881	0,572	0,075	0,021
			bias			0,002	0,045	-0,013	0,047	2,560	-0,109	3,206	0,751	0,147	0,744	0,758
	α_π=2.0		vol.	0,784	1,2	1,049	1,397	1,213	1,846	2,680	0,132	3,198	2,071	0,641	0,077	0,023
			bias			0,001	0,034	-0,015	0,035	2,580	-0,106	3,195	0,897	0,235	0,740	0,766
	α_π=2.5		vol.	0,784	1,2	1,051	1,403	1,217	1,874	2,690	0,130	3,188	2,233	0,709	0,078	0,032
			bias			0,001	0,025	-0,015	0,025	2,590	-0,104	3,185	1,017	0,318	0,735	0,759
		α_u=1.0	vol.	0,681	48,4	1,032	1,587	1,313	2,198	3,120	0,140	3,221	1,410	0,411	0,082	0,020
			bias			-0,002	0,080	-0,033	0,089	2,960	-0,112	3,218	0,545	0,095	0,708	0,764
		α_u=1.5	vol.	0,728	11,6	1,035	1,494	1,261	2,013	2,960	0,138	3,222	1,633	0,493	0,075	0,022
			bias			0,001	0,066	-0,021	0,069	2,820	-0,110	3,218	0,546	0,063	0,726	0,752
ρ=0.7	α_π=1.0	α_u=2.0	vol.	0,829	2,8	1,046	1,351	1,186	1,729	2,630	0,137	3,220	1,690	0,516	0,073	0,022
			bias			0,003	0,058	-0,012	0,061	2,540	-0,112	3,217	0,581	0,056	0,748	0,741
		α_u=2.5	vol.	0,895	0,0	1,056	1,266	1,143	1,555	2,380	0,137	3,219	1,762	0,540	0,067	0,021
			bias			0,004	0,056	-0,007	0,058	2,320	-0,114	3,217	0,609	0,051	0,770	0,733

Table 2c - Monetary policy effectiveness with full transparency

(decreasing gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and π-π^e are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; k^* is the optimal capital-output ratio; i and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

				W	*RR*	Δy	π	π-π^e	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.72	α_π=1.4	α_u=2.3	vol.	-0,026	0,0	1,053	1,202	1,096	1,443	0,350	0,124	2,967	1,557	4,169	0,036	0,022
			bias			-0,014	-0,163	-0,010	-0,128	0,130	-0,088	2,965	0,595	3,897	0,214	0,780
ρ=0.8			vol.	0,947	0,0	1,044	1,260	1,134	1,582	0,360	0,126	2,998	1,316	3,098	0,038	0,027
			bias			-0,016	-0,145	-0,001	-0,143	0,130	-0,087	2,997	0,532	2,816	0,220	0,811
ρ=0.6			vol.	0,968	0,0	1,031	1,252	1,122	1,507	0,350	0,128	2,965	1,654	4,474	0,034	0,023
			bias			-0,012	-0,155	-0,022	-0,105	0,120	-0,089	2,962	0,719	4,227	0,211	0,768
ρ=0.5	α_π=1.0	α_u=2.0	vol.	0,930	0,0	1,022	1,303	1,149	1,591	0,340	0,131	2,969	1,835	4,924	0,033	0,022
			bias			-0,008	-0,137	-0,037	-0,059	0,120	-0,090	2,966	0,802	4,667	0,207	0,753
ρ=0.4			vol.	0,880	0,0	1,013	1,363	1,182	1,695	0,340	0,134	2,977	2,006	5,264	0,033	0,021
			bias			-0,004	-0,113	-0,052	-0,008	0,120	-0,090	2,974	0,880	4,990	0,204	0,742
ρ=0.3			vol.	0,832	0,0	1,006	1,426	1,218	1,806	0,340	0,137	2,987	2,162	5,522	0,032	0,021
			bias			0,001	-0,087	-0,067	0,044	0,120	-0,091	2,983	0,953	5,230	0,202	0,733
	α_π=0.5		vol.	0,987	0,0	1,033	1,233	1,112	1,481	0,350	0,128	2,970	1,507	3,975	0,036	0,027
			bias			-0,015	-0,161	-0,012	-0,134	0,130	-0,089	2,968	0,747	3,731	0,216	0,783
	α_π=1.0		vol.	0,990	0,0	1,039	1,223	1,106	1,473	0,350	0,126	2,971	1,473	3,878	0,036	0,025
			bias			-0,015	-0,161	-0,010	-0,138	0,130	-0,089	2,969	0,633	3,631	0,215	0,786
ρ=0.7	α_π=1.5	α_u=2.0	vol.	0,990	0,0	1,046	1,217	1,106	1,473	0,350	0,123	2,973	1,465	3,795	0,036	0,024
			bias			-0,015	-0,160	-0,008	-0,140	0,130	-0,088	2,971	0,530	3,542	0,215	0,788
	α_π=2.0		vol.	0,987	0,0	1,053	1,214	1,106	1,481	0,350	0,122	2,975	1,479	3,725	0,036	0,024
			bias			-0,016	-0,158	-0,006	-0,141	0,130	-0,087	2,973	0,440	3,464	0,214	0,789
	α_π=2.5		vol.	0,983	0,0	1,060	1,214	1,107	1,494	0,350	0,120	2,977	1,511	3,669	0,036	0,024
			bias			-0,016	-0,157	-0,005	-0,141	0,130	-0,086	2,975	0,362	3,396	0,213	0,789
		α_u=1.0	vol.	0,791	2,4	1,020	1,451	1,243	1,927	0,360	0,137	3,041	1,213	2,282	0,039	0,027
			bias			-0,013	-0,106	-0,010	-0,115	0,140	-0,088	3,038	0,527	2,044	0,220	0,844
		α_u=1.5	vol.	0,937	0,0	1,028	1,283	1,146	1,600	0,360	0,128	2,998	1,297	3,056	0,037	0,028
ρ=0.7	α_π=1.0		bias			-0,016	-0,141	-0,006	-0,141	0,130	-0,089	2,996	0,568	2,830	0,218	0,814
		α_u=2.0	vol.	0,990	0,0	1,039	1,223	1,106	1,473	0,350	0,126	2,971	1,473	3,878	0,036	0,025
			bias			-0,015	-0,161	-0,006	-0,138	0,130	-0,089	2,969	0,633	3,631	0,215	0,786
		α_u=2.5	vol.	0,998	0,0	1,049	1,210	1,098	1,445	0,350	0,127	2,969	1,765	4,802	0,035	0,020
			bias			-0,009	-0,152	-0,023	-0,083	0,120	-0,090	2,966	0,802	4,514	0,211	0,765

Table 3a - Monetary policy effectiveness under no transparency

(constant gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and $\pi\text{-}\pi^e$ are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; k^* is the optimal capital-output ratio; i and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

ρ	α_π	α_u		W	RR	Δy	π	$\pi\text{-}\pi^e$	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.31	α_π=0.3	α_u=3.2	vol.	-0,026	0,0	1,112	1,136	1,074	1,16	1,93	0,15	3,22	1,801	0,575	0,064	0,018
			bias			0,004	0,047	-0,018	0,05	1,92	-0,12	3,22	0,884	0,024	0,783	0,621
ρ=0.8			vol.	0,747	26,4	1,038	1,497	1,25	2,05	3,23	0,13	3,22	1,776	0,571	0,07	0,023
			bias			0,002	0,052	-0,03	0,05	3,03	-0,10	3,22	0,589	0,014	0,71	0,722
ρ=0.6			vol.	0,872	1,2	1,052	1,314	1,16	1,63	2,58	0,13	3,21	1,737	0,552	0,07	0,019
			bias			0,002	0,044	-0,02	0,04	2,49	-0,11	3,21	0,715	0,080	0,75	0,700
ρ=0.5	α_π=1.0	α_u=2.0	vol.	0,915	0,8	1,058	1,269	1,14	1,52	2,44	0,14	3,21	1,700	0,537	0,07	0,019
			bias			0,002	0,042	-0,02	0,04	2,37	-0,11	3,21	0,731	0,096	0,76	0,693
ρ=0.4			vol.	0,929	0,4	1,062	1,250	1,13	1,47	2,36	0,14	3,21	1,690	0,532	0,07	0,020
			bias			0,002	0,041	-0,02	0,04	2,30	-0,11	3,21	0,744	0,107	0,76	0,688
ρ=0.3			vol.	0,941	0,4	1,066	1,236	1,12	1,43	2,30	0,14	3,21	1,679	0,527	0,07	0,022
			bias			0,002	0,041	-0,02	0,04	2,25	-0,11	3,21	0,752	0,115	0,76	0,685
	α_π=0.5		vol.	0,850	5,2	1,044	1,351	1,18	1,71	2,78	0,14	3,22	1,582	0,522	0,07	0,020
			bias			0,002	0,059	-0,03	0,06	2,66	-0,11	3,22	0,501	-0,014	0,74	0,689
	α_π=1.0		vol.	0,824	4,8	1,045	1,380	1,20	1,78	2,84	0,13	3,22	1,770	0,567	0,07	0,021
			bias			0,002	0,046	-0,03	0,05	2,71	-0,10	3,21	0,678	0,055	0,74	0,710
ρ=0.7	α_π=1.5	α_u=2.0	vol.	0,793	4,0	1,047	1,413	1,21	1,86	2,89	0,13	3,21	1,980	0,627	0,07	0,023
			bias			0,002	0,037	-0,03	0,04	2,76	-0,10	3,21	0,843	0,111	0,73	0,732
	α_π=2.0		vol.	0,775	3,6	1,051	1,435	1,23	1,92	2,92	0,13	3,20	2,182	0,687	0,07	0,026
			bias			0,001	0,031	-0,03	0,03	2,78	-0,09	3,20	0,995	0,158	0,73	0,751
	α_π=2.5		vol.	0,741	2,0	1,056	1,474	1,25	2,01	2,93	0,13	3,20	2,422	0,762	0,07	0,031
			bias			0,001	0,027	-0,03	0,03	2,78	-0,09	3,20	1,147	0,196	0,72	0,760
		α_u=1.0	vol.	0,790	67,2	1,025	1,460	1,24	1,96	3,15	0,14	3,22	1,295	0,393	0,07	0,020
			bias			-0,003	0,062	-0,04	0,06	2,96	-0,11	3,21	0,627	0,072	0,72	0,718
		α_u=1.5	vol.	0,770	22,4	1,035	1,468	1,24	1,96	3,15	0,13	3,22	1,627	0,517	0,07	0,021
ρ=0.7	α_π=1.0		bias			0,000	0,058	-0,04	0,06	2,96	-0,10	3,22	0,621	0,049	0,72	0,715
		α_u=2.0	vol.	0,824	4,8	1,045	1,380	1,20	1,78	2,84	0,13	3,22	1,770	0,567	0,07	0,021
			bias			0,002	0,046	-0,03	0,05	2,71	-0,10	3,21	0,678	0,055	0,74	0,710
		α_u=2.5	vol.	0,889	0,8	1,057	1,293	1,15	1,61	2,53	0,13	3,21	1,857	0,592	0,07	0,021
			bias			0,002	0,040	-0,02	0,04	2,44	-0,10	3,21	0,730	0,066	0,75	0,707

Table 3b - Monetary policy effectiveness with full transparency

(constant gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and π-π^e are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; k^* is the optimal capital-output ratio; i and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

				W	RR	Δy	π	π-π^e	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.26	α_π=0.7	α_u=3.0	*vol.*	-0,025	0,0	1,106	1,118	1,064	1,137	1,950	0,147	3,213	1,731	0,577	0,058	0,027
			bias			0,003	0,045	-0,017	0,043	1,930	-0,121	3,211	0,661	0,073	0,793	0,642
ρ=0.8			*vol.*	0,794	23,6	1,033	1,416	1,213	1,896	3,050	0,133	3,215	1,645	0,561	0,067	0,025
			bias			0,002	0,049	-0,028	0,050	2,880	-0,101	3,212	0,559	0,073	0,728	0,743
ρ=0.6			*vol.*	0,900	0,8	1,052	1,266	1,140	1,536	2,490	0,135	3,208	1,634	0,559	0,065	0,022
			bias			0,002	0,045	-0,024	0,045	2,410	-0,109	3,206	0,675	0,119	0,763	0,718
ρ=0.5	α_π=1.0	α_u=2.0	*vol.*	0,931	0,4	1,057	1,231	1,122	1,449	2,370	0,135	3,207	1,611	0,551	0,063	0,023
			bias			0,002	0,044	-0,023	0,043	2,310	-0,111	3,205	0,694	0,133	0,769	0,709
ρ=0.4			*vol.*	0,949	0,4	1,061	1,211	1,111	1,394	2,300	0,136	3,205	1,597	0,547	0,063	0,025
			bias			0,002	0,043	-0,022	0,043	2,250	-0,113	3,203	0,705	0,144	0,771	0,704
ρ=0.3			*vol.*	0,945	0,0	1,064	1,208	1,109	1,375	2,260	0,137	3,204	1,605	0,552	0,063	0,027
			bias			0,002	0,043	-0,023	0,044	2,200	-0,114	3,202	0,718	0,158	0,773	0,703
	α_π=0.5		*vol.*	0,879	4,0	1,045	1,298	1,153	1,611	2,660	0,136	3,223	1,482	0,526	0,067	0,023
			bias			0,003	0,060	-0,028	0,064	2,560	-0,108	3,220	0,464	0,007	0,752	0,706
	α_π=1.0		*vol.*	0,842	3,2	1,045	1,334	1,173	1,693	2,730	0,134	3,211	1,672	0,573	0,068	0,024
			bias			0,002	0,046	-0,026	0,045	2,620	-0,105	3,209	0,642	0,101	0,748	0,731
ρ=0.7	α_π=1.5	α_u=2.0	*vol.*	0,817	2,8	1,046	1,362	1,189	1,762	2,780	0,131	3,200	1,867	0,637	0,069	0,023
			bias			0,001	0,034	-0,025	0,032	2,650	-0,101	3,198	0,795	0,191	0,743	0,753
	α_π=2.0		*vol.*	0,795	2,4	1,048	1,388	1,203	1,830	2,820	0,129	3,191	2,063	0,713	0,071	0,021
			bias			0,000	0,023	-0,024	0,021	2,680	-0,098	3,188	0,929	0,275	0,737	0,762
	α_π=2.5		*vol.*	0,771	1,6	1,051	1,417	1,219	1,902	2,830	0,127	3,182	2,268	0,796	0,073	0,028
			bias			-0,001	0,015	-0,024	0,013	2,700	-0,094	3,180	1,050	0,354	0,732	0,754
		α_u=1.0	*vol.*	0,779	60,8	1,023	1,453	1,233	1,949	3,140	0,135	3,210	1,283	0,435	0,072	0,020
			bias			-0,002	0,061	-0,039	0,065	2,950	-0,106	3,207	0,610	0,147	0,722	0,748
		α_u=1.5	*vol.*	0,772	16,8	1,034	1,438	1,224	1,907	3,090	0,135	3,213	1,573	0,539	0,069	0,022
ρ=0.7	α_π=1.0		*bias*			0,000	0,056	-0,035	0,058	2,910	-0,103	3,210	0,602	0,110	0,727	0,739
		α_u=2.0	*vol.*	0,842	3,2	1,045	1,334	1,173	1,693	2,730	0,134	3,211	1,672	0,573	0,068	0,024
			bias			0,002	0,046	-0,026	0,045	2,620	-0,105	3,209	0,642	0,101	0,748	0,731
		α_u=2.5	*vol.*	0,901	0,0	1,057	1,256	1,135	1,532	2,440	0,134	3,210	1,755	0,598	0,066	0,025
			bias			0,002	0,042	-0,021	0,042	2,370	-0,107	3,208	0,678	0,098	0,768	0,724

Table 3c - Monetary policy effectiveness with full transparency

(constant gain learning)

The table reports a summary of the results (500 replications) of the model simulations (for the initial 140 periods). For each set of parameters of the central bank's interest-rate rule, mean *(bias)* and standard deviation *(volatility)* with respect to the steady-state values are reported (in p.p.). *W* stands for welfare (as a ratio to the optimum, reported in row 1) and *RR* for the rejection rate; Δy is the growth rate of GDP, π and π-π^e are actual and surprise inflation; Δw is wage growth; Θ_0 is the mean intercept of the forecasting equations for inflation; $\Delta\pi$ is the difference between central bank and private-sector inflation expectations; *k** is the optimal capital-output ratio; *i* and i^e are the actual and expected short-term (policy) interest rate; i^L is the yield on Treasury bonds; $H(\pi^e)$ and $H(i^e)$ are the entropy associated, respectively, with the choice of the forecasting model for π^e and i^e.

				W	RR	Δy	π	π-π^e	Δw	Θ_0	$\Delta\pi^e$	k^*	i	i^L	$H(\pi^e)$	$H(i^e)$
ρ=0.72	α_π=1.1	α_u=2.5	vol.	-0,026	0,0	1,061	1,191	1,089	1,411	0,350	0,127	2,968	1,619	4,359	0,036	0,031
			bias			-0,013	-0,160	0,026	-0,117	0,130	-0,087	2,966	0,666	4,061	0,214	0,740
ρ=0.8			vol.	0,947	0,0	1,045	1,253	1,129	1,565	0,360	0,126	3,005	1,295	2,999	0,038	0,034
			bias			-0,016	-0,140	0,024	-0,141	0,130	-0,082	3,003	0,528	2,712	0,221	0,787
ρ=0.6			vol.	0,971	0,0	1,039	1,239	1,114	1,481	0,350	0,129	2,967	1,608	4,274	0,034	0,030
			bias			-0,014	-0,156	0,022	-0,115	0,130	-0,088	2,965	0,681	4,024	0,212	0,733
ρ=0.5	α_π=1.0	α_u=2.0	vol.	0,934	0,0	1,031	1,286	1,137	1,555	0,350	0,132	2,966	1,775	4,689	0,033	0,028
			bias			-0,011	-0,144	0,013	-0,081	0,120	-0,089	2,964	0,746	4,427	0,208	0,715
ρ=0.4			vol.	0,889	0,0	1,024	1,341	1,166	1,651	0,340	0,136	2,970	1,933	5,001	0,033	0,026
			bias			-0,008	-0,127	0,004	-0,043	0,120	-0,089	2,967	0,806	4,723	0,205	0,700
ρ=0.3			vol.	0,841	0,0	1,017	1,400	1,196	1,754	0,340	0,139	2,975	2,080	5,239	0,032	0,026
			bias			-0,005	-0,109	-0,006	-0,006	0,120	-0,089	2,971	0,861	4,941	0,202	0,690
	α_π=0.5		vol.	0,988	0,0	1,038	1,221	1,105	1,456	0,350	0,130	2,976	1,455	3,798	0,036	0,032
			bias			-0,016	-0,157	0,025	-0,136	0,130	-0,087	2,974	0,697	3,549	0,217	0,751
	α_π=1.0		vol.	0,991	0,0	1,044	1,213	1,103	1,454	0,350	0,127	2,977	1,440	3,723	0,036	0,032
			bias			-0,016	-0,157	0,026	-0,139	0,130	-0,086	2,975	0,612	3,472	0,216	0,757
ρ=0.7	α_π=1.5	α_u=2.0	vol.	0,989	0,0	1,050	1,210	1,103	1,459	0,350	0,124	2,979	1,447	3,660	0,036	0,032
			bias			-0,016	-0,157	0,027	-0,141	0,130	-0,085	2,977	0,536	3,402	0,216	0,763
	α_π=2.0		vol.	0,985	0,0	1,056	1,209	1,104	1,470	0,350	0,122	2,980	1,472	3,608	0,036	0,031
			bias			-0,016	-0,156	0,028	-0,142	0,130	-0,084	2,979	0,468	3,341	0,215	0,769
	α_π=2.5		vol.	0,977	0,0	1,063	1,211	1,106	1,487	0,350	0,120	2,982	1,514	3,568	0,036	0,031
			bias			-0,016	-0,156	0,029	-0,143	0,130	-0,083	2,980	0,410	3,289	0,214	0,774
ρ=0.7	α_π=1.0	α_u=1.0	vol.	0,793	4,0	1,017	1,447	1,233	1,919	0,360	0,137	3,047	1,225	2,235	0,039	0,030
			bias			-0,014	-0,101	0,008	-0,113	0,140	-0,081	3,044	0,547	1,991	0,220	0,826
		α_u=1.5	vol.	0,936	0,0	1,030	1,277	1,142	1,588	0,360	0,128	3,004	1,291	2,964	0,037	0,034
			bias			-0,016	-0,136	0,021	-0,137	0,130	-0,085	3,003	0,576	2,731	0,219	0,790
		α_u=2.0	vol.	0,991	0,0	1,044	1,213	1,103	1,454	0,350	0,127	2,977	1,440	3,723	0,036	0,032
			bias			-0,016	-0,157	0,026	-0,139	0,130	-0,086	2,975	0,612	3,472	0,216	0,757
		α_u=2.5	vol.	0,995	0,0	1,058	1,199	1,092	1,419	0,350	0,128	2,967	1,683	4,551	0,035	0,029
			bias			-0,012	-0,157	0,024	-0,104	0,130	-0,088	2,965	0,716	4,260	0,212	0,733

Table 4 - Sensitivity analysis: number of replications

(decreasing gain learning)

Each entry in the table is the ratio between the value of the first or second moment of welfare, output growth and inflation computed on 10,000 and 500 replications. For output growth and inflation not only the mean, but also the maximum, minumum and the median of each set of replications are presented.

NO TRANSPARENCY

Welfare ratio = 0.991

volatility ratios

	max	min	mean	median
Δy	1,036	0,845	1,010	1,006
π	1,172	0,924	1,000	1,003

bias ratios

	max	min	mean	median
Δy	1,110	1,016	1,041	1,125
π	1,096	0,360	1,005	1,010

PARTIAL TRANSPARENCY

Welfare ratio = 0.990

volatility ratios

	max	min	mean	median
Δy	1,046	0,848	1,011	1,008
π	1,167	0,898	1,000	1,002

bias ratios

	max	min	mean	median
Δy	1,113	1,000	1,043	1,143
π	1,073	0,457	1,005	1,020

FULL TRANSPARENCY

Welfare ratio = 0.989

volatility ratios

	max	min	mean	median
Δy	1,066	0,889	1,012	1,020
π	1,078	0,894	1,001	1,008

bias ratios

	max	min	mean	median
Δy	1,352	1,010	0,993	0,987
π	0,990	1,324	1,002	0,997

Table 5 - Sensitivity analysis: initial conditions

(decreasing gain learning)

The table reports the ranking in terms of welfare of the competiting policy rules for a set of values of the Γ matrix (the normalising factor of the generalised stochastic gradient algorithm). The values of Γ considered are (1) the one used in the baseline simulations; (2) Γ scaled up and down by 10 p.p.; (3) Γ multiplied by 1.25 and 0.75; (4) Γ set equal to 1.5 and 0.5 times the benchmark value. As in the previous tables, only the initial 140 observations are used in computing the welfare ranking. For each policy rule, the model is simulated 500 times. Each row of the table refers to a policy rule, while the columns are divided into three subgroups, corresponding to the alternative monetary regimes (i.e. no transparency, partial transparency and full transparency). In the last two rows of the table, the Spearman's and Kendall's rank correlation coefficients are shown.

	no transparency							***partial transparency***							***full transparency***						
kΓ where k is:	1	0,9	1,1	3/4	5/4	1/2	3/2	1	0,9	1,1	3/4	5/4	1/2	3/2	1	0,9	1,1	3/4	5/4	1/2	3/2
optimal policy	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
ρ=0.8	12	13	12	13	12	12	13	12	12	13	13	13	13	13	9	9	10	9	9	9	9
ρ=0.6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	8	8	8	8	8	8	8
ρ=0.5 $\alpha_\pi=1.0$ $\alpha_u=2.0$	4	4	4	4	4	4	4	4	4	5	4	4	4	4	11	11	9	11	11	11	11
ρ=0.4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	12	12	12	12	12	12	12
ρ=0.3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	13	14	13	13	13	13	13
$\alpha_\pi=0.5$	7	7	7	7	7	7	7	8	7	7	7	7	7	7	6	7	4	7	5	6	6
$\alpha_\pi=1.0$	8	8	8	8	8	8	8	7	8	8	8	8	8	8	4	5	3	4	3	4	3
ρ=0.7 $\alpha_\pi=1.5$ $\alpha_u=2.0$	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	3	5	3	4	3	4
$\alpha_\pi=2.0$	11	10	10	10	11	11	11	10	10	10	10	10	10	10	5	4	6	5	6	5	5
$\alpha_\pi=2.5$	10	11	11	11	10	10	10	11	11	11	11	11	11	11	7	6	7	6	7	7	7
$\alpha_u=1.0$	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	13	14	14	14	14	14
ρ=0.7 $\alpha_\pi=1.0$ $\alpha_u=1.5$	13	12	13	12	13	13	12	13	13	12	12	12	12	12	10	10	11	10	10	10	10
$\alpha_u=2.5$	5	5	5	5	5	5	5	5	5	4	5	5	5	5	2	2	2	2	2	2	2
Spearman *ρ (%)*		0,99	0,99	0,99	1,00	1,00	0,99		0,99	0,98	0,99	0,99	0,99	0,99		0,98	0,96	0,99	0,99	1,00	0,99
Kendall *τ (%)*		0,95	0,97	0,95	1,00	1,00	0,97		0,97	0,92	0,95	0,95	0,95	0,95		0,92	0,87	0,97	0,95	1,00	0,97

Table 6a - Sensitivity analysis: specification of the welfare function

(no transparency)

The table reports the rankings in terms of welfare of the competiting policy rules for alternative specifications of the welfare function. The parameter ω is the weight attached to the unconditional variance of the interest rate (σ^2 while the parameter ζ and (1-ζ) measure, respectively, the relevance of inflation (σ^2_π) and output growth ($\sigma^2_{\Delta y}$ volatility. Each row of the table corresponds to a policy rule, while the columns refer to alternative values of the weights of the interest rate and inflation objectives relative to that of output growth.In the last two rows of the table, the Spearman's and Kendall's rank correlation coefficients are shown.

Welfare function: $-[\zeta\sigma^2_\pi+(1-\zeta)\sigma^2_{\Delta y}+\omega\sigma^2_i]$

			ω/1-ζ (for ζ=0.5):						ζ/1-ζ (for ω=0):						
ρ	*α*		0	1/10	1/4	1/2	3/4	9/10	1/4	1/2	3/4	5/4	6/4	7/4	2
ρ=0.3	*α_π=0.4*	*α_u=3.5*	*1*	*1*	*1*	*4*	*7*	*7*	*6*	*1*	*1*	*1*	*1*	*1*	*1*
ρ=0.8			*13*	*13*	*12*	*12*	*11*	*11*	*13*	*13*	*13*	*13*	*13*	*13*	*13*
ρ=0.6			*6*	*5*	*5*	*6*	*6*	*6*	*5*	*6*	*6*	*6*	*6*	*6*	*6*
ρ=0.5	*α_π=1.0*	*α_u=2.0*	*4*	*4*	*4*	*3*	*4*	*4*	*3*	*4*	*4*	*4*	*4*	*4*	*4*
ρ=0.4			*3*	*3*	*3*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*	*3*	*3*
ρ=0.3			*2*	*2*	*2*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*	*2*
	α_π=0.5		*7*	*7*	*6*	*5*	*3*	*3*	*7*	*7*	*7*	*7*	*7*	*7*	*7*
	α_π=1.0		*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*
ρ=0.7	*α_π=1.5*	*α_u=2.0*	*9*	*9*	*9*	*11*	*12*	*12*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
	α_π=2.0		*11*	*10*	*13*	*13*	*13*	*13*	*10*	*11*	*11*	*11*	*11*	*11*	*11*
	α_π=2.5		*10*	*12*	*14*	*14*	*14*	*14*	*11*	*10*	*10*	*10*	*10*	*10*	*10*
		α_u=1.0	*14*	*14*	*10*	*9*	*5*	*5*	*14*	*14*	*14*	*14*	*14*	*14*	*14*
ρ=0.7	*α_π=1.0*	*α_u=1.5*	*12*	*11*	*11*	*10*	*10*	*10*	*12*	*12*	*12*	*12*	*12*	*12*	*12*
		α_u=2.0	*9*	*9*	*9*	*11*	*12*	*12*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
		α_u=2.5	*5*	*6*	*7*	*7*	*9*	*9*	*4*	*5*	*5*	*5*	*5*	*5*	*5*
Spearman ρ				*0,98*	*0,90*	*0,84*	*0,59*	*0,59*	*0,93*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*
Kendall τ				*0,93*	*0,76*	*0,63*	*0,43*	*0,43*	*0,87*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*

Table 6b - Sensitivity analysis: specification of the welfare function

(partial transparency)

The table reports the rankings in terms of welfare of the competiting policy rules for alternative specifications of the welfare function. The parameter ω is the weight attached to the unconditional variance of the interest rate (σ^2 while the parameter ζ and (1-ζ) measure, respectively, the relevance of inflation (σ^2_π) and output growth (σ^2_{Δ} volatility. Each row of the table corresponds to a policy rule, while the columns refer to alternative values of the weights of the interest rate and inflation objectives relative to that of output growth.In the last two rows of the table, the Spearman's and Kendall's rank correlation coefficients are shown.

Welfare function: $-[\zeta\sigma^2_\pi+(1-\zeta)\sigma^2_{\Delta y}+\omega\sigma^2_i]$

ρ	α_π	α_u	ω/1-ζ (for ζ=0.5):						ζ/1-ζ (for ω=0):						
			0	1/10	1/4	1/2	3/4	9/10	1/4	1/2	3/4	5/4	6/4	7/4	2
ρ=0.26	*α_π=0.7*	*α_u=3.2*	*1*	*1*	*1*	*4*	*6*	*6*	*6*	*1*	*1*	*1*	*1*	*1*	*1*
ρ=0.8			*12*	*13*	*11*	*12*	*11*	*11*	*13*	*13*	*13*	*12*	*12*	*12*	*12*
ρ=0.6			*6*	*6*	*5*	*6*	*5*	*5*	*5*	*6*	*6*	*6*	*6*	*6*	*6*
ρ=0.5	*α_π=1.0*	*α_u=2.0*	*4*	*4*	*4*	*3*	*4*	*4*	*3*	*4*	*4*	*4*	*4*	*4*	*4*
ρ=0.4			*3*	*3*	*3*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*	*3*	*3*
ρ=0.3			*2*	*2*	*2*	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*	*2*
	α_π=0.5		*8*	*7*	*7*	*5*	*3*	*3*	*8*	*8*	*8*	*8*	*8*	*8*	*8*
	α_π=1.0		*7*	*8*	*8*	*8*	*8*	*8*	*7*	*7*	*7*	*7*	*7*	*7*	*7*
ρ=0.7	*α_π=1.5*	*α_u=2.0*	*9*	*9*	*9*	*11*	*12*	*12*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
	α_π=2.0		*10*	*10*	*13*	*13*	*13*	*13*	*10*	*10*	*10*	*10*	*10*	*10*	*10*
	α_π=2.5		*11*	*12*	*14*	*14*	*14*	*14*	*11*	*11*	*11*	*11*	*11*	*11*	*11*
		α_u=1.0	*14*	*14*	*12*	*9*	*9*	*7*	*14*	*14*	*14*	*14*	*14*	*14*	*14*
ρ=0.7	*α_π=1.0*	*α_u=1.5*	*13*	*11*	*10*	*10*	*10*	*10*	*12*	*12*	*12*	*13*	*13*	*13*	*13*
		α_u=2.0	*7*	*8*	*8*	*8*	*8*	*8*	*7*	*7*	*7*	*7*	*7*	*7*	*7*
		α_u=2.5	*5*	*5*	*6*	*7*	*7*	*9*	*4*	*5*	*5*	*5*	*5*	*5*	*5*
Spearman ρ				*0,98*	*0,92*	*0,82*	*0,74*	*0,66*	*0,93*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*
Kendall τ				*0,93*	*0,80*	*0,60*	*0,52*	*0,45*	*0,87*	*0,98*	*0,98*	*1,00*	*1,00*	*1,00*	*1,00*

Table 6c - Sensitivity analysis: specification of the welfare function

(full transparency)

The table reports the rankings in terms of welfare of the competiting policy rules for alternative specifications of the welfare function. The parameter ω is the weight attached to the unconditional variance of the interest rate (σ^2 while the parameter ζ and (1-ζ) measure, respectively, the relevance of inflation (σ^2_{π}) and output growth (σ^2 $_{\Delta}$ volatility. Each row of the table corresponds to a policy rule, while the columns refer to alternative values of the weights of the interest rate and inflation objectives relative to that of output growth.In the last two rows of the table, the Spearman's and Kendall's rank correlation coefficients are shown.

Welfare function: $-[\zeta\sigma^2_{\pi}+(1-\zeta)\sigma^2_{\Delta y}+\omega\sigma^2_{i}]$

ρ	α_{π}	α_{u}	ω/1-ζ (for ζ=0.5):						ζ/1-ζ (for ω=0):						
			0	1/10	1/4	1/2	3/4	9/10	1/4	1/2	3/4	5/4	6/4	7/4	2
ρ=0.72	*α_{π}=1.4*	*α_{u}=2.3*	*1*	*3*	*7*	*8*	*9*	*9*	*8*	*3*	*1*	*1*	*1*	*1*	*1*
ρ=0.8			*9*	*7*	*2*	*2*	*2*	*2*	*10*	*10*	*9*	*9*	*9*	*9*	*9*
ρ=0.6			*8*	*10*	*9*	*10*	*10*	*10*	*3*	*7*	*8*	*8*	*8*	*8*	*8*
ρ=0.5	*α_{π}=1.0*	*α_{u}=2.0*	*11*	*11*	*12*	*12*	*12*	*12*	*7*	*11*	*11*	*11*	*11*	*11*	*11*
ρ=0.4			*12*	*12*	*13*	*13*	*13*	*13*	*11*	*12*	*12*	*12*	*12*	*12*	*12*
ρ=0.3			*13*	*14*	*14*	*14*	*14*	*14*	*13*	*13*	*13*	*13*	*13*	*13*	*13*
	α_{π}=0.5		*6*	*5*	*6*	*6*	*7*	*7*	*1*	*1*	*5*	*7*	*7*	*7*	*7*
	α_{π}=1.0		*4*	*2*	*3*	*4*	*4*	*5*	*2*	*2*	*3*	*4*	*5*	*5*	*5*
ρ=0.7	*α_{π}=1.5*	*α_{u}=2.0*	*3*	*1*	*1*	*3*	*3*	*4*	*4*	*5*	*4*	*3*	*3*	*3*	*3*
	α_{π}=2.0		*5*	*4*	*5*	*5*	*5*	*6*	*9*	*6*	*6*	*5*	*4*	*4*	*4*
	α_{π}=2.5		*7*	*6*	*8*	*7*	*8*	*8*	*12*	*8*	*7*	*6*	*6*	*6*	*6*
		α_{u}=1.0	*14*	*13*	*11*	*9*	*6*	*3*	*14*	*14*	*14*	*14*	*14*	*14*	*14*
ρ=0.7	*α_{π}=1.0*	*α_{u}=1.5*	*10*	*8*	*4*	*1*	*1*	*1*	*6*	*9*	*10*	*10*	*10*	*10*	*10*
		α_{u}=2.0	*4*	*2*	*3*	*4*	*4*	*5*	*2*	*2*	*3*	*4*	*5*	*5*	*5*
		α_{u}=2.5	*2*	*9*	*10*	*11*	*11*	*11*	*5*	*4*	*2*	*2*	*2*	*2*	*2*
Spearman ρ				*0,83*	*0,55*	*0,36*	*0,24*	*0,10*	*0,59*	*0,90*	*0,99*	*1,00*	*0,99*	*0,99*	*0,99*
Kendall τ				*0,74*	*0,43*	*0,27*	*0,21*	*0,14*	*0,43*	*0,78*	*0,96*	*0,98*	*0,96*	*0,96*	*0,96*

Table 7 - Sensitivity analysis: impact of initial conditions on predictor proportions

The table shows the limiting behaviour of predictor proportions under fixed and random initial conditions. The first column lists the forecasting models used for forming expectations (7 for the short-term interest rate; 5 for inflation: 2 for the exchange rate). The next columns show - for each of the 3 variables - 4 statistics: the average (across replications) share of population selecting model *i* under random ($\boldsymbol{x}^r$) and fixed ($\boldsymbol{x}^f$) initial conditions; the standardised difference ($\boldsymbol{z}$) between $\boldsymbol{x}^r$ and $\boldsymbol{x}^f$; the correlation ($\boldsymbol{\rho}$) between random initial conditions and limit values of predictor proportions. The denominator of $\boldsymbol{z}$ is the simple average of the standard deviations of the limit values of predictor proportions under random and fxed initial conditions.

	Short-term Interest Rate				**Inflation**				**Exchange Rate**			
	$\boldsymbol{x}^r$	$\boldsymbol{x}^f$	$\boldsymbol{z}$	$\boldsymbol{\rho}$	$\boldsymbol{x}^r$	$\boldsymbol{x}^f$	$\boldsymbol{z}$	$\boldsymbol{\rho}$	$\boldsymbol{x}^r$	$\boldsymbol{x}^f$	$\boldsymbol{z}$	$\boldsymbol{\rho}$
PLM #1	0,000	0,000	0,000	-0,034	0,000	0,000	0,000	0,029	0,687	0,634	0,206	0,555
PLM #2	0,006	0,006	-0,003	0,755	0,319	0,265	0,479	0,795	0,313	0,366	-0,206	0,555
PLM #3	0,149	0,158	-0,320	0,872	0,050	0,053	-0,021	0,671	–	–	–	–
PLM #4	0,449	0,464	-0,539	0,837	0,517	0,574	-0,502	0,735	–	–	–	–
PLM #5	0,000	0,000	0,000	0,022	0,113	0,108	0,045	0,628	–	–	–	–
PLM #6	0,396	0,372	0,862	0,556	–	–	–	–	–	–	–	–
PLM #7	0,000	0,000	0,000	0,024	–	–	–	–	–	–	–	–

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