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Dynamics of consumer inflation with irrational expectations and exogenous economic shocks

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Abstract

Aim: Economic modelling has long relied on the assumption of individual rationality. Advances in the behavioural sciences and the problematic empirical fit of rational models have made this central assumption increasingly untenable. The article proposes an alternative and more realistic approach to model agents as forming diverse expectations.

Methodology: The study leverages the approach of heterogeneous expectations and shows how to formally incorporate behavioural heuristics into the expectations formation process. It presents the setup and computation of a small dynamic stochastic general equilibrium (DSGE) model, based on heterogeneous expectations and compares its dynamics to the rational expectations benchmark.

Results: The DSGE model shows that an economy with heterogeneous expectations generates business cycles of its own through the mechanism of self-fulfilling prophecies. As agents' expectations diverge from rationality, the economy drifts away from its potential output and extreme inflation episodes ensue. A comparison with empirical data from the European Union serves to further corroborate and validate model insights.

Implications and recommendations: This outcome underlines the importance of sentiments as drivers of price dynamics and proposes a viable alternative for modelling them. The results show the importance of complementing current mainstream modelling with more psychological insights on the microfoundations of agent behaviour to better approximate the workings of the economic system.

Originality/value: The paper shows how alternative expectations formation mechanisms can be incorporated into a small DSGE model, and provides a simple but realistic way to formal model herding and validates its results through a comparison with actual statistical data from the European Union.

Keywords: macroeconomic model, inflation, prices, simulation, heterogeneous expectations, DSGE, behavioural macroeconomics

1. Introduction

Economic expectations bring crucial repercussions to macroeconomics dynamics. From the early research on adaptive and rational expectations, the field's growing understanding is that expectations tend to be heterogeneous, and often irrational. The paper considers a standard definition of irrationality as either failing to maximise a benefit, or as following inconsistent preferences (Kacelnik, 2006). This has implications not only for individual-level decision-making, but also for the overall fluctuations in output and inflation. This article builds upon data from an economic experiment and supplements a traditional macroeconomic model with a mechanism for forming and switching to different models of expectations formation. Such computable macroeconomic models are key tools for understanding both the inner workings of the economic systems as well as guides for formulating and implementing monetary and fiscal policy. A standard approach is to define the economy-wide supply and demand functions, to postulate a process for the interest rates and to put forward additional equations modelling the aggregate behaviour of the agents (Gali, 2015).

Economic expectations are a crucial component of the model as they influence the overall demand and supply for goods, services, and capital. Following the tradition of rationality in economic modelling, agents' expectations are often formulated as homogeneous rational expectations (Gali, 2015), implying that all agents form one and the same expectation, which is also an unbiased statistical forecast given the available information. Advances in the social and behavioural sciences show that agents barely conform to this view (Hommes, 2011; Branch, 2004). Instead, they tend to use simple rules and form different, or heterogeneous, sets of expectations. While some authors do question the relevance of identifying expectations for policy-making (Rudd, 2022), the overwhelming consensus appears to agree on their importance. Recent research by Burke and Ozdagli (2023) shows that expectations do have some effect on actual consumption, particularly of non-durables. Changing consumer expectations are also shown to have effects on the savings and borrowing cycles of households (Claus, & Nguyen, 2023).

The author explored the possibilities of constructing a macroeconomic model based on heterogeneous expectations and compared its results to a model based on homogeneous rational expectations, also incorporating herding behaviour in the model to show how it amplifies output and price dynamics. The simulated economy model was then run through 10,000 iterations and its key characteristics were outlined. The study also sought empirical support for the model presented by investigating the links between consumer sentiment and actual realised inflation in the EU countries over a relatively long period of time.

2. Literature review

Theoretical macroeconomic models often mathematically derive the expectation formation mechanism by modelling agents as homogeneous optimising units (Gali, 2015). Other approaches relax this assumption by allowing for some heterogeneity (Grandmont, 1998; Evans, & Honkapohja, 2001a). Such a mechanism of a priori setting of the forecasting mechanisms begs the question of how well the empirical data correspond to the theoretical assumptions.

2.1. Expectations formation

The main hypotheses for the formation of economic expectations were conditioned by both the historical context of the development of economic thought, and the available data and tools. Despite some limitations, the theories of expectations formation have been largely developed against the backdrop of traditional approaches to provide a satisfactory explanation of basic facts of economic reality. Adaptive expectations have been displaced by rational ones under the pressure of the inexplicable stagflation of the 1970s in the USA and the inability of the Phillips curve with adaptive expectations to explain economic dynamics. Newer approaches, such as expectations based on learning or heterogeneous information, are gaining relevance given the accumulation of considerable evidence on the bounded rationality of individuals and the inability of perfectly rational models to explain speculative episodes such as the early-decade dot-com crash and the financial-economic crisis which started in 2007-8 (Colander et al., 2009; Kirman, 2010).

Given the accumulated knowledge from behavioural economics and the global economic crisis, a rethinking of the modified rationality paradigm and an attempt at a psychologically-based modelling of economic agents as constrained optimizing individuals using a set of heuristics, is placed on the agenda.

The earliest to appear, the **static expectations** approach, is the simplest model for representing the formation of agents' attitudes about future system dynamics. They assume that with low volatility of the predicted variable and with limited information and/or rationality of the agent, it is logical for them to extrapolate to the next period in the future the value of the given variable in the current period (Evans, & Honkapohja, 2001a), i.e.

$$E_t[x^e{}_{t+1}] = x_t. \tag{1}$$

If the agents extrapolate the current trend, then one has an unambiguously defined and available measure of their expectations. Moreover, some results from behavioural economics show that it is possible that some agents use simple heuristics in their forecasting (Barberis, & Thaler, 2002), which points to the idea that static expectations may describe the behaviour of some agents. Empirical research suggests that a number of agents do indeed fit this description (Branch, 2004). Although this approach allows for highly limited cognitive effort on the part of agents, it serves as a natural idealised point of suboptimal behaviour as it implies the use of an absolute minimum of information and is used as a borderline case in modelling (Chen et al., 2008).

Adaptive expectations, formally introduced in the 1950s and 1960s by Nerlove (1958), Cagan (1956), and Friedman (1957), emerged as the next step in the more realistic modelling of expectations. This kind of mechanism of defining expectations is based on the idea that economic agents form their beliefs about the future in a certain way and then revise these expectations according to the observed realizations, namely they adapt their expectations to the actual development of the economic environment by a certain (constant) coefficient of proportionality λ, as in

$$E_t[x_{t+1}] = E_t[x_{t+1}] + \lambda(x_t - E_t[x_{t+1}]). \tag{2}$$

In this case, coefficient λ is seen as the relative weight that the agent gives to the realisation in the current period and to the formed expectations, respectively. At $\lambda = 1$, the adaptive mechanism becomes a static one. Despite its simplicity, laboratory experiments showed that participants' expectations tend to track realised prices, and thus this approach still remains useful (Holt et al., 2017).

Rational expectations carry over the main approaches and conclusions of utility theory to model agents – they are modelled as perfectly rational individuals, both in making intertemporal optimization decisions and in making the maximum use of the full possible set of information in forecasting of their decision-relevant variables (Sent, 1999). In one of the earliest definitions, Muth (1961) defined rational expectations as matching the prediction of economic theory for the specified variable. If one denotes by Θ_t the set of all available information that is relevant to the estimated value of a certain variable, then rational expectations can be expressed by the following equation

$$E_t[x_{t+1}]= E[x_{t+1}|\Theta_t]. \tag{3}$$

In practice, this means that in forming the expectation for a given variable, such as the price level, agents will use the entire available time series of values, include other variables that are relevant to the process (e.g. output gap and structure of shocks), and will use the best possible economic model to formulate their forecast. It is important to emphasise that the rational expectations hypothesis does not assume that economic agents' forecasts are necessarily infallible. There may be large deviations between expected and realised values, but rationality dictates that in the presence of systematic error, agents will eliminate it in order to improve their forecast (Mishkin, 1983). This means that the expected error on the available information in the long run is zero, i.e.

$$E[x_{t+1} - x_t|\Theta_t] = 0. \tag{4}$$

Despite significant strides in economic modelling, research suggests that leveraging rational expectations as the only way of forming economic expectations seems to be insufficient to capture the complexities of the process (Coibion et al., 2018; Thaler, 2016).

The next step in this research programme was the idea of the formation of **expectations through learning** by economic agents, one of the first formalisations being by Sargent (1993), and further developed by a number of authors, most notably Evans and Honkapohja (2001a). The main idea in this approach was that economic agents do not have the opportunity to fully observe the structure of the economy, the values of the parameters and the exact relationships between them, i.e. they do not observe the "real law of motion" of the system. The authors attempted to estimate, and then update, the unknown parameters, forming perceptions of the system's law of motion (Evans, & Honkapohja, 2001a). If one denotes by x_t the variable (or vector of variables) to be predicted, by $x^e{}_t$ – the expectations, by Y_t – a vector of observable variables, and by θ_t – a vector of variables that evolve with respect to time, then adaptive learning implies

$$x^e{}_t = \Psi(Y_t, \theta_{t-1}). \tag{5}$$

In adaptive learning, the predictive rule Ψ is based on a certain econometric model (i.e. a perception of the law of motion), and vector θ is a vector of unknown parameters that must be calculated so that the rule is applied. The forecast is completed by adding a rule for calculating and updating the data used

$$\theta_t = \wp(t, \theta_{t-1}, Y_t). \tag{6}$$

It is worth noting that this approach often leads to asymptotically achieving rational expectations (Evans, & Honkapohja, 2001a, 2001b).

Empirical research on the formation of aggregate expectations shows that the heterogeneity of the expectations of individual economic agents is key to understanding the process (Branch, 2004; Branch, & Evans, 2006). Such heterogeneity may be due to different predictive rules (heterogeneous agents, see e.g. Brock, & Hommes, 1997) or to different access to available information (heterogeneous information, see e.g. Carroll, 2001). If information is heterogeneous, this means that different groups of economic agents use different information sets in the formation of their forecasts, so that even if the formation mechanism is the same (rational or not), the final result is highly likely to be different (Mankiw et al., 2004; Carroll, 2003). Thus, the aggregate expectations in the economy will be a weighted sum of the individual heterogeneous expectations, multiplied by the proportion of agents who have access to the given information set (λ_i), i.e.

$$E_t[x_{t+1}] = \sum_{i=1}^{n} \lambda_i E\left[x_{t+1,i}\middle|\Theta_{t,i}\right], \quad \sum_{i=1}^{n} \lambda_i = 1. \tag{7}$$

Heterogeneous information can also be interpreted from a different perspective – the different information upon which agents form their expectations could be due to the frequency with which they update the data they use for forecasting. Assuming that a fixed fraction updates its data in the given period and the rest of the public does not, the following relationship holds (see Carroll, 2001)

$$E_t[x_{t+1}] = \lambda E_t[x_{t+1}|\Theta_t] + (1-\lambda)[\lambda E_{t-1}[x_t|\Theta_{t-1}] +$$
$$+ (1-\lambda)\lambda E_{t-2}\left[x_{t-1}\middle|\Theta_{t-2}\right] + (1-\lambda)\lambda^j E_{t-j}\left[x_{t+1-j}\middle|\Theta_{t-j}\right]. \tag{8}$$

Evolutionary expectations are an attempt to respond to the criticism that expectations based on heterogeneous information (empirically difficult to distinguish from those based on heterogeneous agents) cannot sufficiently model real behaviour and, moreover, lack a mechanism to describe the emergence of heterogeneity as an endogenous process. Essentially, this approach is an attempt to model overall economic expectations as a weighted sum of different forecasts, where the weights are determined by an evolutionary switching mechanism (Brock, & Hommes, 1997; Hommes, 2011). To illustrate this, a vector of values of the variable to be predicted was defined as

$$X_t = (x_t, x_{t-1}, \dots, x_{t-n}). \quad (9)$$

Each agent has different prediction methods, denote the vector of them as H_t, so that $H_t = \big(H_1(X_{t-1}), H_2(X_{t-1}), \dots, H_K(X_{t-1})\big)$. Following this, one can denote the expectations formed by a given forecasting method as x^e_{t+1} and express the aggregate expectations as follows

$$x^e{}_{t+1} = \sum_{j=1}^{K} n_{j,t} E\left[x_{t+1} \middle| H_{j,t}\right]. \quad (10)$$

The greater the utility of the specific approach, the more likely it is to be used in a subsequent period. The switching mechanism between different approaches is often with a discrete choice logistic model (cf. Manski, & McFadden, 1981), and this mechanism can be thought of as an instance of reinforcement learning (Brock, & Hommes, 1997). The most commonly used empirical approach to test this mechanism is the simulation of expectations and their subsequent comparison with actually generated expectations under the same conditions (see Hommes et al., 2005; Pfajfar, & Zakelj, 2009; de Grauwe, 2010; Hommes, 2021). It should be noted that the behaviour of realistic markets seems to be well described by the heterogeneous expectations approach observing both actual macroeconomic data as well as data from economic experiments (Hommes et al., 2019; Hommes, 2021; Assenza et al., 2021). In fact, even simple specifications of the heuristic mechanism using adaptive and trend-extrapolating heuristics provide a useful approximation to behaviour (Anufriev et al., 2019). Moreover, research has uncovered other behavioural biases and heuristics that may be potentially important for understanding behaviour such as the herding bias – the tendency of agents to align their behaviour with that of others (see e.g. Duxbury, 2015; Virigineni, & Rao, 2017; Gerunov, 2019; Atanasov, 2019; Koetsier, & Bikker, 2022; Mand, 2023). Herding behaviour has been a prominent feature of economic and financial markets since at least the 1990s (Scharfstein, & Stein, 1990; Devenow, & Welch, 1996), and one should see the excellent review articles by Spyrou (2013) and Komalasari et al. (2022) for a more comprehensive overview.

2.2. Empirical work on expectations formation

Survey data are actively being used in the study of economic dynamics, with uncertainty in intertemporal optimisation problems receiving increasing attention (Knotek, & Khan, 2011). Although the measurement of expectations has its methodological peculiarities and problems (Dominitz, & Manski, 2003), modern macroeconomic theory considers the survey data as an adequate approximation of the actually formed expectations and accordingly includes them in the process of the modelling and evaluation of policies (Tsenova, 2011; Clark, & Nakata, 2008; Cooper, & Willis, 2010). Due to the key role of the Phillips curve, inflation forecasting has traditionally been of particular interest to macroeconomists, and thus a number of studies focused on this segment of expectations. The extensive use of surveys in empirical research naturally raises the question of whether stated inflation expectations correlate with actual behaviour. Armantier et al. (2015) tested whether stated survey expectations correlated with those revealed in an investment experiment, and found that there was reasonable correlation which only breaks down for less educated respondents, thus giving credence to the usage of survey data to investigate expectations.

Using a series of vector autoregression models on data from the Livingston Survey, Mehra and Herrington (2008) found that expected inflation is mainly influenced by realised inflation, the change in the prices of basic goods and by movements in itself (i.e. autocorrelation dependence). This study, along with some others (Gurkaynak et al., 2007), provided some evidence that temporary shocks to the economy led to weaker effects on individuals' expectations in the last two decades than in preceding ones. The overall results suggest that the central bank policy should largely be aimed at anchoring expectations so that the economic system is more forward-looking. The anchoring of expectations crucially depends on the general dynamics – depending on the changes of the environment, agents intelligently change their behaviour. Carroll (2001, 2003) modelled expectations as informed by news coverage of inflation and found very different dynamics depending on the extent to which inflation was a significant issue accordingly covered in the media. Roos (2005) also confirmed that agents place more effort into forming precise expectations when the marginal gain from doing so exceeds the marginal cost of the effort. Empirical data strongly questioned the economic assumption of a representative agent forming homogeneous expectations on the basis of complete information about the economic system. Examining the price level expectations of a representative panel of Americans, de Bruin et al. (2010) found clear trends and influence of demographic factors and financial literacy. A trend was revealed for females, the unmarried, the poorer and the older to have significantly higher inflation expectations. This result was further supported by Coibion et al. (2018), who used survey data on companies in New Zealand, finding that they tended to form expectations of inflation higher than those of professional forecasters. Moreover, Coibion et al. (2018) established that there was significant heterogeneity in those expectations, which tend to be updated in a Bayesian manner as new pertinent economic information becomes available. The authors also suggested that this process was quite imperfect as companies display “rational inattention” – they judge the cost of obtaining new information against the benefits, and sometimes choose not to pay the price for the update. For a recent review on the rational inattention literature, see also the excellent review by Maćkowiak et al. (2023). Coibion et al. (2020) further detailed the different types of information that agents may (not) use in the formation of their expectations – including those priors – and perception of inflation, shopping experience, information from the media, and knowledge about monetary policy.

The correlation of expectations with certain demographic variables was also observed in other databases, e.g. that of the University of Michigan. Souleles (2004) examined the error structure of these data and found a relationship between it and the demographic structure of the sample. Using data on the German economy from the Centre for European Studies at the University of Mannheim, Lux (2009) showed the significant effect of social influences on the overall assessment of the business environment. These results can be interpreted within the framework of the Keynesian understanding that irrational sentiments, which cover broad groups of agents simultaneously, determine economic dynamics.

General market sentiment is also potentially important in many other situations (Duffy, 2008; Chauvet, & Guo, 2003; de Grauwe, 2012), which often may have serious consequences at systemic level such as in the formation and collapse of financial bubbles (Lux, 1995). Such observations are consistent with empirical and experimental data on individual behaviour at microeconomic level (Camerer, 2003). These research findings cast doubt on the rationality of formed expectations, a theme widely advocated in contemporary research. Carroll (2003) estimated that agents do not make full use of all available information – data show that they update their information set once a year, which generates significant macro-level inflexibility. Moreover, Bordalo et al. (2020) discovered markedly behavioural traits in the formation of expectations – most notably, individual professional forecasters may overreact to individual news, while the consensus forecast typically underreacts to the news, hinting at some level of heterogeneity with potentially important macroeconomic effects.

A similar result was reached by Roos (2005), examining the differences between user and expert forecasts. Exploration of the error structure of the Michigan survey data also led to rejection of the hypothesis that expectations are formed strictly rationally (Souleles, 2004). In a comprehensive study of economic expectations, Golinelli and Parigi (2004) examined time series for eight countries from the 1970s to 2002 on a quarterly basis and found that the results of a vector autoregression model with the most often used macroeconomic indicators did not fully overlap with agents’ expectations. Direct tests of rationality on survey data also led to results that contradicted the assumptions of the rational formation hypothesis (Mankiw et al., 2004). Coibion and Gorodnichenko (2015) also tested the assumption of rationality using surveys of professional and non-professional forecasters in the USA and from a sample of other countries. They established that the null hypothesis of forming rational expectations was rejected and considered this evidence of information rigidities, proposing that imperfect information models may be better suited to understand expectation formation.

The ability of sociological data to predict future dynamics beyond the possibilities of currently known macro variables was also well established in a number of other studies – see e.g. Curtin (2007) and Ang et al. (2007). Although expectations are not rational in the narrow economic sense, their influence on economic dynamics is significant and hence their forecasting capabilities should not be underestimated. Examining data from the survey in the University of Michigan, Pfajfar and Santoro (2010) indicated that heterogeneity was a major feature of measured expectations, and divided them into three main types: the first – highly autoregressive, the second – close to rationality, while in the third the expectations correspond to the hypotheses of adaptive learning and imperfect information. Using an evolutionary switching mechanism between heuristics, Branch (2004) showed that such behaviour describes remarkably well the empirical realisations of the University of Michigan survey.

The research results of Branch (2004) were largely confirmed in later work (Branch, 2007), where the rational, adaptive, and static expectations heuristics were tested against a slow information update model (Mankiw, & Reis, 2002). The evolutionary switching model received wider empirical confirmation, leading to the conclusion that uncertainty in the model is a more important factor in determining expectations than information imperfection. Moreover, rational agents may find it optimal to consider only a limited number of approaches within a confined set of information when forming their expectations and making their decisions (cf. Matejka, 2016; Caplin et al., 2019; Jung et al., 2019; Stevens, 2020). The ever expanding literature that investigates rational inattention provides ample and rich evidence that different information sets and different cost-benefit calculations give rise to significant heterogeneity in the way economic actors form their expectations (cf. Maćkowiak et al., 2023 and the references therein). In a recent paper, Cornand and Hubert (2021) collated and compared inflation expectation data from surveys, policymakers, and experiments and distinguished five types of agents in terms of their expectations: households, industry, professional forecasters, policy-makers, and individuals who elected to become experimental subjects. The study revealed significant heterogeneity among the groups, with the households and companies being at large variance with the reference level.

To sum up, the available evidence strongly points to the hypothesis that observable expectations are formed as a result of the use of a range of different forecasting mechanisms, each of which is used by a variable proportion of the observed sample at different points in time.

3. Model specification and parameterisation

A standard way to approach modelling the macroeconomy is to define aggregate demand and supply functions based on micro-foundations, and simulate their dynamics to study an aggregate of interest (see e.g. Melosi, 2017). Behavioural macroeconomic models proved to be a useful tool for investigating how individual level bounded rationality or heterogeneity is able to affect the dynamics of inflation and output (Gabaix, 2020), and such models also provide results that are at great variance with traditional rational expectations, and at the same time can generate useful policy predictions (ibid.). This paper aimed to leverage a small-scale macroeconomic model that would allow the study of behavioural expectations in the spirit of de Grauwe (2012) and Gabaix (2020), with a particular emphasis on macroeconomic dynamics under irrational expectations and herding. The author referred to a standard New Keynesian model with aggregate demand and supply curves where interest rates follow the Taylor rule, and then operationalised the model using both rational expectations and a combination of rational and adaptive ones (heterogeneous expectations), amplified by herding. The models were simulated using a Monte Carlo mode which allowed to compare and contrast their outcomes.

Following Gali (2015) and de Grauwe (2012), the author described the economy with three key structural equations (see 11) – for aggregate demand, aggregate supply, and a realistic rule governing interest rates, respectively:

$$y_t = a_1 E_t[y_{t+1}] + (1 - a_1) y_{t-1} + a_2 (r_t - E[\pi_{t+1}]) + \varepsilon_t,$$
$$\pi_t = b_1 E[\pi_{t+1}] + (1 - b_1) \pi_{t-1} + b_2 y_t + \eta_t,$$
$$r_t = c_1 \pi_t + c_2 y_t + c_3 r_{t-1} + u_t, \tag{11}$$

where y_t denotes the gap between realised and the natural level of output (or GDP), π_t denotes inflation, and r_t – interest rates at time *t*, with a_i, b_i, c_i – parameters; operator E[·] denotes expectations, and ε_t, η_t, and u_t – normally distributed random error terms with mean 0 and standard deviation of 0.5. Those are terms for proxy exogenous shocks to the economic system. Experimental work showed that agents tend to form expectations using a set of simple rules which they select based on their past performance (Hommes et al., 2019; Hommes, 2021; Assenza et al., 2021). It was established that the set of such rules is consistent with some agents using rational expectations, while others defer to adaptive ones (Anufriev et al., 2019). Therefore, the set of heuristics for forming expectations for output gap y_t consists in rationality H_1 (forecasting the mathematical expectation of the variable under the given information set Θ_t) and habit formation H_2 (or autoregressive behaviour), defined as

$$H_{1,t}(y_{t+1}) = E[y_{t+1} | \Theta_t],$$
$$H_{2,t}(y_{t+1}) = y_t. \tag{12}$$

Moreover, other research emphasised the importance of herding behaviour when economic agents make decisions and form expectations (Duxbury, 2015; Virigineni, & Rao, 2017; Koetsier, & Bikker, 2022; Mand et al., 2023). Experimental evidence also showed that individuals are strongly affected by the choices of others (Gerunov, 2019; Gerunov, 2022), giving more credence to the need to include herding heuristic H_3. This reflects the simple idea that some agents find it rational not to form expectations of their own but rather to adhere to the opinion of the majority. Thus the herding heuristic was defined as

$$H_{3,t} = \begin{cases} H_{1,t}, p_{1,t} > p_{2,t} \\ H_{2,t}, p_{1,t} < p_{2,t} \end{cases}. \tag{13}$$

The aggregated expectations constitutes the weighted sum of all heuristics weighted by the proportion of agents which use them at time *t* ($p_{1,t}$, $p_{2,t}$, and $p_{3,t}$), i.e.

$$E_t[y_{t+1}] = \sum_{i=1}^{n} p^{y}{}_{i,t} H_{i,t}(y_{t+1}). \tag{14}$$

The author also postulated that agents choose what heuristic to use based on its utility (or accuracy) $U^y{}_t$ as measured by the quadratic error of the forecast, employing a logistic discrete choice model (Manski, & McFadden, 1981) to determine probability $p_{i,t}$ of using each one:

$$p^{y}{}_{i,t} = \frac{exp(\beta U^{y}{}_{i,t-1})}{\sum_{i=1}^{3} exp(\beta U^{y}{}_{i,t-1})} \quad i = \{1,2,3\}. \tag{15}$$

Since agents form habits and tend to stick to their preferred heuristic, the increased probability of selecting the heuristic in use was modelled by adding a lagged term and thus obtain (with δ denoting the strength of habits):

$$p^{y}{}_{i,t} = \delta p^{y}{}_{i,t-1} + (1 - \delta) \frac{exp(\beta U^{y}{}_{i,t-1})}{\sum_{i=1}^{3} exp(\beta U^{y}{}_{i,t-1})} \quad i = \{1,2,3\}. \tag{16}$$

In general, this specification attempts to realistically model agents and build macroeconomic expectations from individual behaviour. Initially agents pick a heuristic to form expectations but then they repeatedly test it against reality and only maintain it if this facilitates forecasting. The two major groups of agents are those that either attempt to form a rational expectation and those that rely on the past, with the third group of social agents merely amplifying the dominant market sentiment. As expectations are formed, they influence the law of motion of the economic system through the three structural equations. In this sense, realisations of the output gap and inflation, influence expectations but are also driven by them, creating sophisticated two-directional feedback loops in the economic system. The behavioural macroeconomic model shows how economic dynamics are crucially influenced by market sentiments and how moods could drive the business cycle.

4. Simulation results and discussion

The first step to obtaining quantitative model estimates is to parameterise the behavioural model equations, using plausible values. While parameter values would naturally vary with different economic conditions and context, the author employed a set of relatively standard values found in the literature (see Walsh, 2003; Gali, 2015), which ensures that model results can serve as a useful benchmark and also be compared to other similar investigations; the key parameter values are shown in Table 1. Leveraging those, the model was simulated over 10,000 iterations and its behaviour studied, also simulating the same model with only homogenous rational expectations (namely $H^{y}_{1,t}$ and $H^{\pi}_{1,t}$ are always selected), and the results were then compared. Further simulations under different plausible parameter values showed that qualitative results were not sensitive to specific parameterisations.

Table 1. Key model parameters

Coefficient	Model notation	Value
Effect of expected output	a_1	0.5
Output elasticity to interest rates	a_2	-0.2
Inflation inertia	b_1	0.5
Cyclic influence on inflation	b_2	0.05
Central bank inflation reaction strength	c_1	1.5
Central bank recession reaction strength	c_2	0.5
Interest rate smoothing	c_3	0.5
Normalised inflation target	π^*	0.0
Heuristic switching frequency	B	1
Strength of habits	Δ	0.5

Source: Walsh, 2003; Gali, 2015.

Table 2. Descriptive statistics of the rational and heterogeneous expectations models

Statistic	Rational expectations model			Heterogeneous expectations model		
	Inflation	Output gap	Interest rates	Inflation	Output gap	Interest rates
Mean	0.07	-0.05	0.17	0.01	-0.07	-0.04
St. Dev.	0.56	0.65	1.19	1.12	1.83	2.29
Median	0.07	-0.05	0.17	-0.03	0.01	-0.07
Min	-1.88	-2.65	-4.47	-4.86	-7.25	-9.21
Max	2.10	2.45	4.51	4.90	7.86	8.13
Skewness	-0.02	0.03	-0.02	0.16	-0.25	0.05
Kurtosis	-0.04	0.07	-0.07	0.66	0.94	0.20

Source: author’s calculations.

The model simulation results are shown in Table 2. The model based on heterogeneous expectations has almost the same means as those for the rational expectations, but is characterized by much larger standard deviations of both the output gap and inflation. The mean inflation in both models was around zero, as economic theory suggests that it should be under those specifications. Formally testing this hypothesis revealed that indeed the heterogeneous model does not produce inflation that is statistically different from zero (t(9999) = 0.65, p = 0.52), while the rational expectations model does produce a rate of inflation which is statistically significantly different from zero (t(9999) = 13.01, p < 0.005), but still with a very low mean of 0.07% with little practical significance.

The key difference between these models was that the heterogeneous expectations model produces much wider ranges of variable fluctuations, which applies both to the rate of inflation and the output gap. Inflation dynamics can be observed in Figure 1, where the first panel presents dynamics over the first 500 periods (or 125 simulated years), while the second one provides an overview of inflation dynamics over the full simulation.

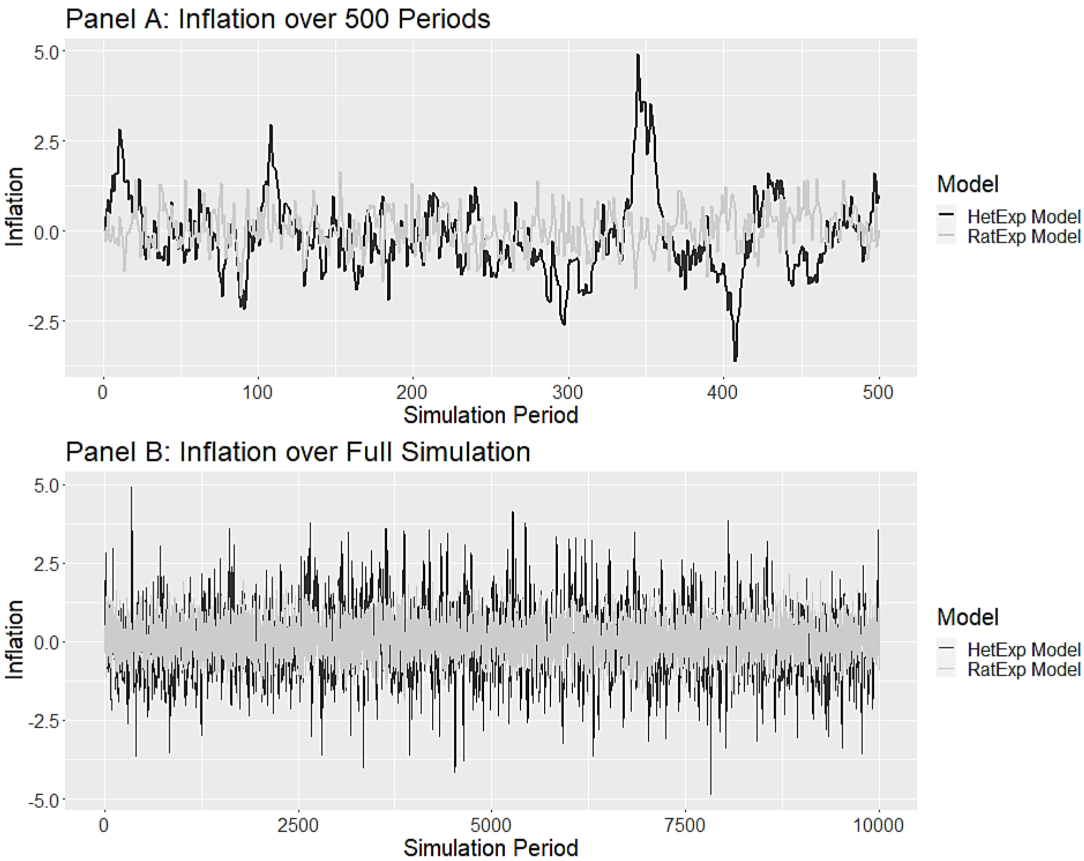

Fig. 1. Inflation dynamics in heterogeneous (HetExp) and rational (RatExp) models

Source: author's calculations.

While both models eventually show inflation returning to low values around zero due to the central bank implementing inflation targeting via a Taylor rule, it is obvious that the economy inhabited by agents dynamically forming expectations by selecting among a set of simple behavioural heuristics is much more volatile. In fact, the behavioural HetExp model produces rates on inflation that can be 2.5 times higher than those under rational expectations, which is reflected in the very different values of the standard deviations (0.56 for the rational model, and 1.12 for the behavioural ones), as well as the notable differences in the range of outcomes: 3.98 p.p. between minimum and maximum for the rational model and 9.76 p.p. for the behavioural one).

The difference in realisation can be easily observed when one compares the two respective density functions of inflation realization in the two models presented in Figure 2. The rational expectations model is clustered around zero with little spread, while the heterogeneous expectations model has significantly fatter tails, allowing for a wider range of realizations that include more instability and periods of higher inflation. In this sense, the HetExp model has a richer and more nuanced view of the economy, while at the same time providing a better empirical fit – episodes of higher inflation are known to have occurred.

Fig. 2. Density functions of realised inflation in heterogeneous (HetExp) and rational (RatExp) models

Source: author's calculations.

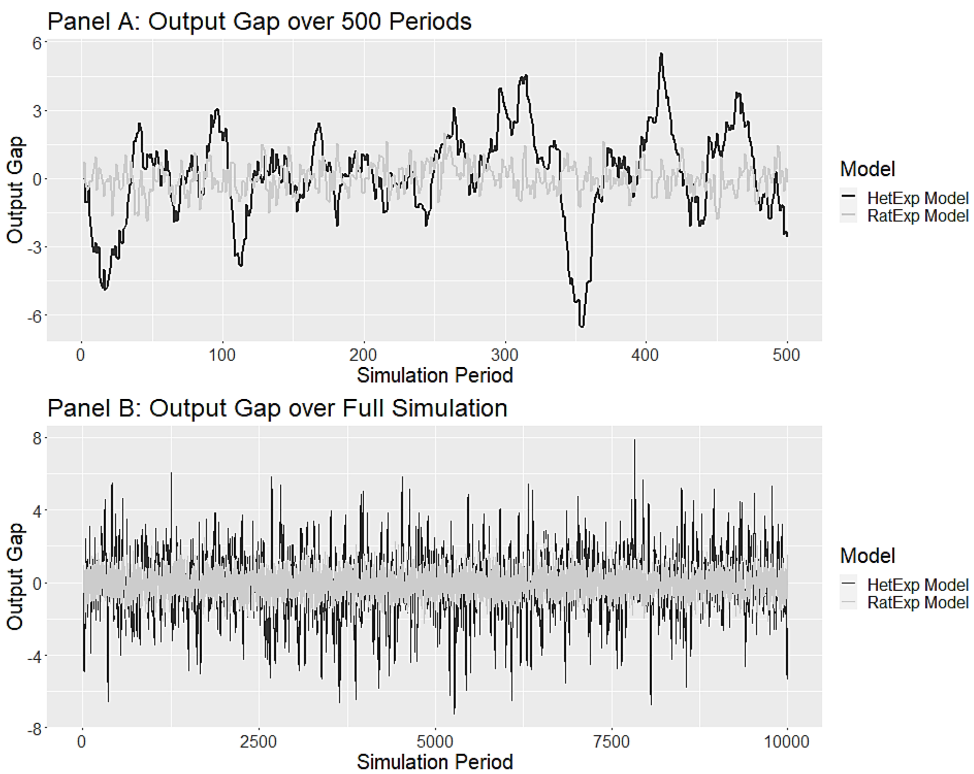

Fig. 3. Output dynamics in heterogeneous (HetExp) and rational (RatExp) models

Source: author's calculations.

There were similar dynamics regarding the realizations of the output gap (see Figure 3). The output gap had much more pronounced volatility under heterogeneous expectations, ranging from a low of -7.25 to a high of 7.86. The rational expectations benchmark model's output gap varied between -2.65

and 2.45. The high volatility of the behavioural model is also reflected in the standard deviation of the output gap – about 3 times as high as the one in the rational benchmark model.

The density functions of output gap realizations show a similar picture (see Figure 4). Once again, the heterogeneous expectations model had fatter tails that provide for the possibility of wider economic fluctuations. Such a model easily accommodated downturns of 8% of GDP, while the rational expectations model (even with a series of exogenous shocks) could only produce very mild recessions of around a 2% drop of production. Knowing that the interest rates follow a version of the Taylor rule, it is hardly surprising that their dynamics are also more pronounced in an economy of evolutionary changing expectations.

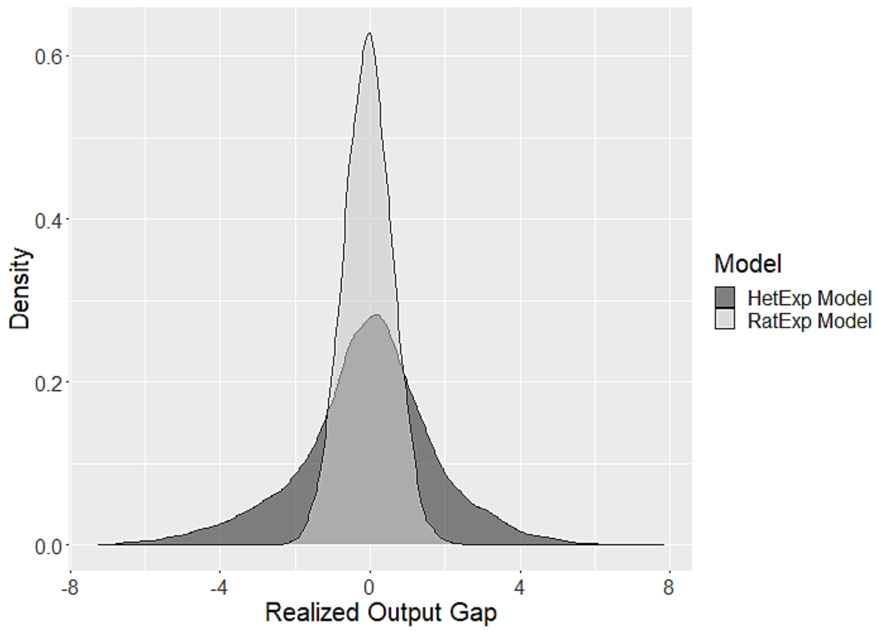

Fig. 4. Density functions of realised output gap in heterogeneous (HetExp) and rational (RatExp) models

Source: author's calculations.

Figures 1 to 4 depict the dynamics of the two models, revealing that both of them capture the economy's natural tendency towards its potential production, but market sentiments in the behavioural model provided for larger and persistent fluctuations around this optimum. Diverse agents form their expectations of inflation and the output and feed them into the economy through their decisions and actions. If, for example, agents expect large inflation deviations they will prepare by modifying their behaviour, which will in turn create the expected fluctuations and validate the initial mood. It is, therefore, possible for an economy to enter its own endogenous business cycle of booms and busts without any change of fundamentals or notable external shocks. Such dynamics are hardly observed under rational expectations – their fluctuations are milder, and the economy soon returns to its fundamental values.

A rational expectations model is largely driven by the normally distributed external shocks, which is also reflected in the normality of distribution of output gap and inflation realisations – with the Jarque-Bera test statistics of $\chi^2 = 3.9$ (p = 0.14) and $\chi^2 = 1.54$ (p = 0.46), respectively. It is a model that cannot endogenously explain market fluctuations and has no real theory of the business cycle. In contrast, the heterogeneous expectations model is exposed to the same normally distributed shocks but generates markedly non-Gaussian realisations (the Jarque-Bera test results were $\chi^2 = 471.1$ for output gap and $\chi^2 = 226.0$ for inflation, both of them significant at levels much below 1%). Hence, this model is able to generate its own dynamics driven by market moods and sentiments, which form the basis of a behaviourally-informed theory of the economic cycle.

A more thorough inspection of how heuristics affect inflation realisation is useful for understanding the overall dynamics of the behavioural model. Figure 5 demonstrates the dynamics of inflation around one of its more pronounced peaks and the share of heuristics used by agents in the system. Panel A shows the peak inflation of 4.90% in period 345, as well as the previous and the next fifty periods, while Panel B shows the relative share of heuristic. At the beginning of the period, agents expect the economy to produce its optimal inflation and act as if this were true. Feeding those expectations into the system in fact leads to this optimum price level, thus validating the sentiment. Rational expectations predominated from period 295 to period 316, and agents who herd also adopt the rational forecast, thus driving inflation to its desired rate of zero.

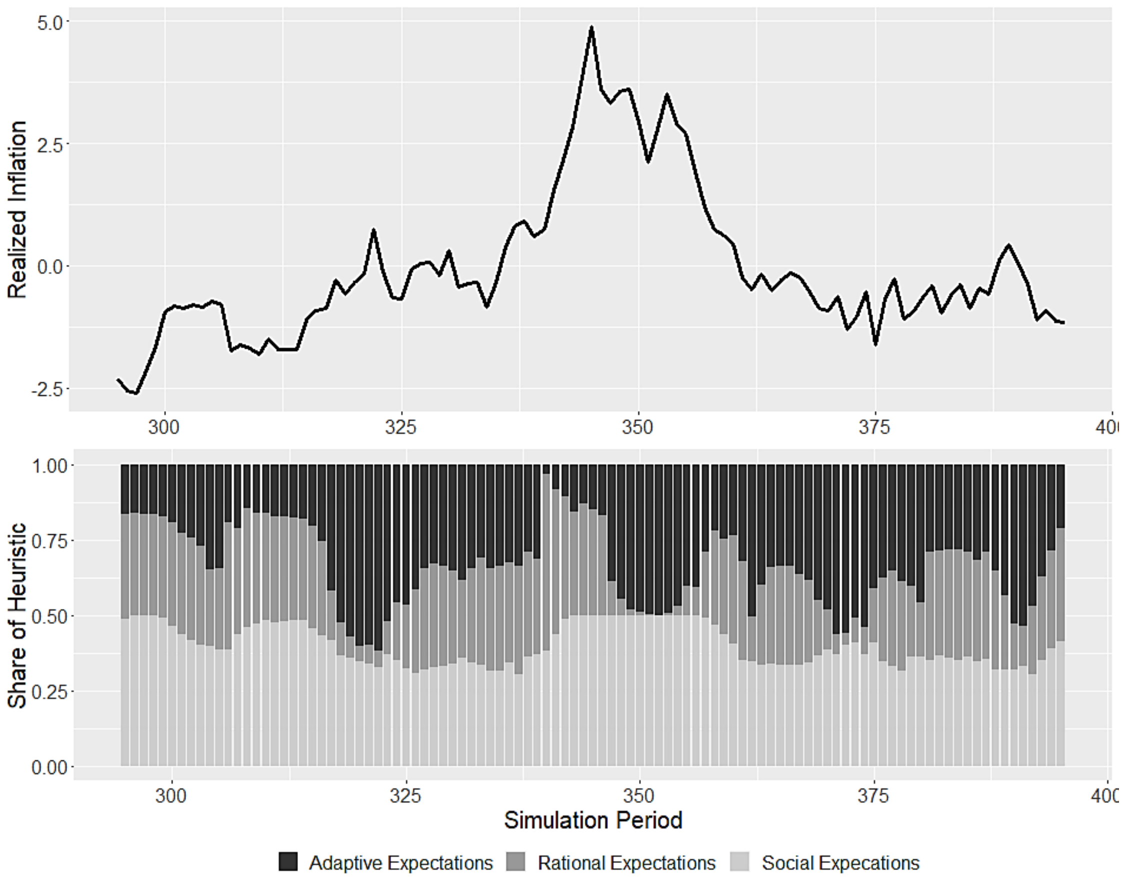

Fig. 5. Inflation volatility and share of heuristics used by agents

Source: Eurostat and author's calculations.

From then on, some random shock shifts inflation dynamics making agents adopt increasingly more adaptive expectations, and social actors who herd, simply follow suit. This de facto leads to persistent rigidity in the system, and inflation begins to rise well above its optimum. At its peak deviation, agents realise that adaptive expectations no longer make sense as they prove consistently wrong, and switch to alternatives – either rational or social ones. As rational expectations take little preponderance over adaptive ones, this is magnified by agents who bandwagon on the majority idea. This effectively leads to a large proportion of the agents using rational expectations, and thus returns the economy to its low inflation regime. Expectations can thus be self-fulfilling prophecies which influence economic dynamics in a very tangible way. Should the sentiment shift due to a preponderance of negative exogenous shocks, extrapolative moods start permeating the system. When adaptive agents dominate the market, inflation can fluctuate wildly above or below its fundamental values. Both sentiments are amplified by the large proportion of agents who do not form a forecast of their own but rather use the social heuristic.

Rationality has been the dominant paradigm in economic modelling, and rational expectations models have informed both private sector decisions and the conduct of economic policy. These models have been very influential and widely accepted until the outbreak of the global financial crisis, which proved their forecasting results and policy recommendations to be disappointing (cf. Kirman, 2010). The heterogeneous agents approach presents a viable alternative which is both more psychologically realistic and provides for better empirical fit, and it results in wide deviations of aggregates from their fundamental values, non-normal statistical distributions and a significant degree of inertia – all of them key characteristics of empirical time series.

The heterogeneous expectations model is more sophisticated than the rational expectations one as it incorporates recent advances in the cognitive and behavioural sciences within the standard macroeconomic framework for stochastic modelling. Its key feature is that the results are much less determinate than under the assumption of rationality. As the economic system is strongly dominated by individual moods, under conducive conditions a small shock can trigger a swing in market sentiment which leads to significant output fluctuations. However, if markets are calm, a large shock may not result in notable deviations of inflation. Even in the face of known magnitude and direction of the shock, the system remains somewhat indeterminate which poses significant challenges for policy, and even more so – for forecasting.

5. Empirical relationship between expectations and actual economic dynamics

The behavioural model thus captures a crucial driver of the business cycle which is not included in traditional rational expectations models – the 'animal instincts' or irrational moods of market participants, which are further amplified by the individual's tendency to display herding behaviour. Its empirical implications are also straightforward – in the real economies, market sentiments and expectations closely parallel the dynamics of key aggregates. The study leveraged data from Eurostat covering all EU countries and the United Kingdom for a total of 28 countries and two aggregated entities (the EU as a whole, and the Eurozone), to formally test whether such a connection exists. The dataset consisted in monthly data on inflation expectations (forward and backward-looking), expectations on the general economic environment and consumer sentiments. To measure inflation, the author used data for the Harmonised Index of Consumer Prices (HICP) for realised inflation with respect to the previous period, and also to the period 12 months before, spanning from January 2000 to December 2022. Even a brief visual inspection of the data shows the close link between inflation expectations and realised inflation. Figure 6 depicts inflation perceptions for the past 12 months against the realised inflation, and inflation expectations against the realised inflation. Across the panel there appears to be a robust link between inflation expectations and actual price hikes, and the correlation matrix lends further credence to that. There was a strong and statistically significant correlation between backward-looking inflation expectations and realised month-on-month inflation ($r = 0.51$), as well as between forward-looking inflation expectations and price hikes ($r = 0.58$). The former can be hypothesised to proxy adaptive expectations, while the latter are more in line with rational expectations. One should note that forward-looking expectations are correlated with current (and not future) inflation, lending further credence to the hypothesis that agents act now on expectations, thus affecting current economic dynamics. This is also broadly consistent with the transmission mechanisms outlined in the behavioural model.

Other types of expectations are far more weakly related to price dynamics. Expectations on overall economic conditions over the past and next 12 months, as well as the consumer sentiment indicator, are statistically significantly related to inflation but the link is much weaker. If economic expectations are indeed a strong driver of overall macroeconomic dynamics, then one would expect that different variables that proxy expectations will be in a cointegration relationship with measures of inflation. This was formally tested using Johansen's (1991) cointegration test and presenting results for cointegration between five measures of economic expectations and price increases.

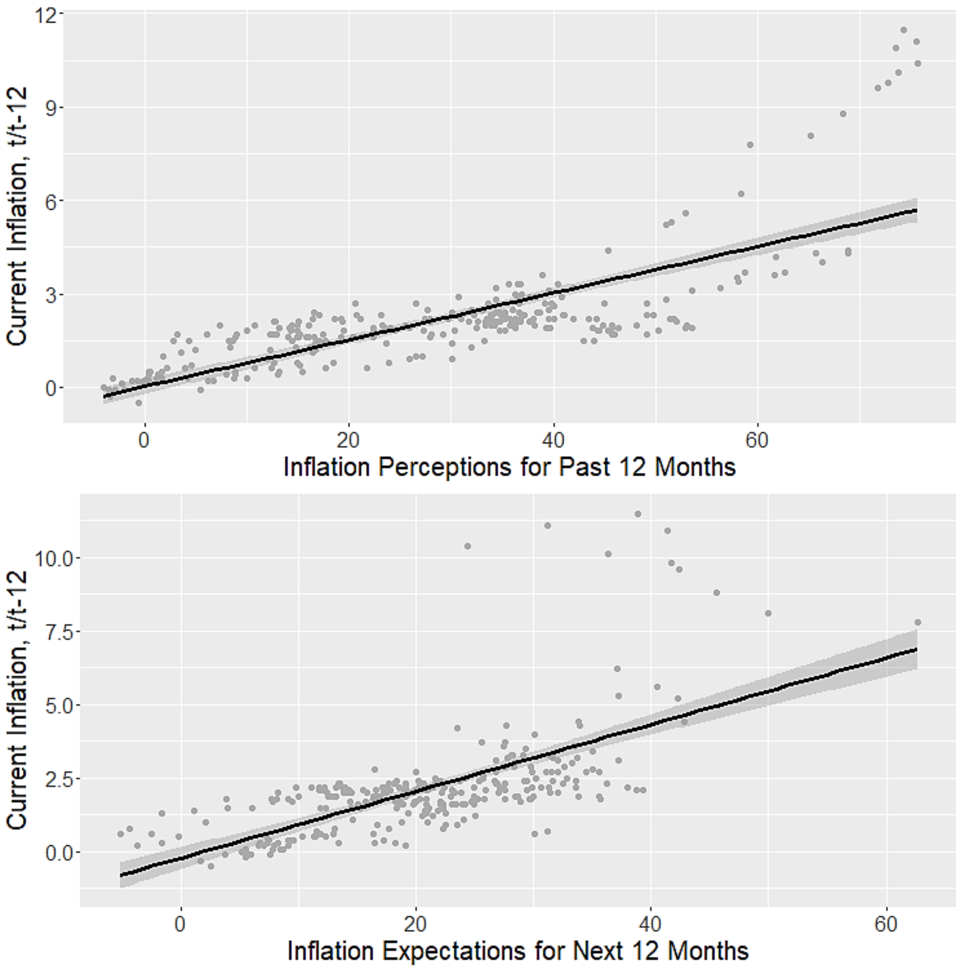

Fig. 6. Forward and backward-looking inflation expectations against realised inflation in the EU

Source: Eurostat.

Table 3. Correlation matrix between expectations and measures of realised inflation

	Consumer confidence	Economic situation, next 12m	Economic situation, previous 12m	Inflation expectations, next 12m	Inflation expectations, previous 12m	Inflation: HICP t/t-1	Inflation: HICP t/t-12
Consumer confidence	1.00	0.83	0.79	-0.10	-0.33	-0.18	-0.05
Economic situation, next 12m	0.83	1.00	0.79	-0.18	-0.33	-0.21	-0.07
Economic situation, previous 12m	0.79	0.79	1.00	0.05	-0.30	-0.14	-0.04
Inflation expectations, next 12m	-0.10	-0.18	0.05	1.00	0.49	0.51	0.23
Inflation expectations, previous 12m	-0.33	-0.33	-0.30	0.49	1.00	0.58	0.19
Inflation current month over previous month	-0.18	-0.21	-0.14	0.51	0.58	1.00	0.38
Inflation current month over previous year	-0.05	-0.07	-0.04	0.23	0.19	0.38	1.00

Source: author's calculations.

Table A1 (Appendix A) shows the test results of HICP for the previous 12 months, while Table A2 (Appendix A) tests cointegration with price growth over one month. As the Johansen procedure sets the null of no cointegration, the test statistic must be above 12.91 to reject the null with 90% confidence, at 14.90 to reject it with 95% confidence, and at 19.19 to reject it with 99% confidence. Forward-looking inflation expectations for the next 12 months were almost uniformly cointegrated with current inflation, with a few notable exceptions – Hungary, Malta, Germany, and the UK. Backward-looking inflation expectations show a more mixed picture, where countries with relatively lower GDP per capita demonstrate a more robust cointegration. Forward-looking expectations about the overall economic situations also appear to be more robustly cointegrated with inflation rather than backward-looking ones. Consumer confidence was cointegrated with inflation expectations in 13 out of the 30 entities under study (see Table A1 in Appendix A).

The cointegration relationship was much stronger when tested for realised month-on-month inflation (Table A2 in Appendix A). In this case the author could reject the null of no cointegration for every single type of economic expectations under study for every single country or entity in the dataset, which provided sufficient credence to the idea that agent expectations are closely connected to price dynamics. While expectations are formulated as considerations for the future, it seems that they are actually very closely connected to current price volatility.

This first look at the empirical data underlines the plausibility of the behavioural model with herding proposed here. The data were broadly consistent with their main implications – the effect on expectations, the interplay between backward-looking (adaptive) and forward-looking (rational) expectations and the much broader range of realisations of inflation as opposed to the rational model. Moreover, realised inflation in the EU was even more volatile than what the model predicted, which further supports the idea that a model needs a mechanism to introduce larger shocks to aggregates which can create endogenous business cycles with widely divergent inflation dynamics. The herding mechanism essentially serves to amplify irrationality (adaptive expectations) and thus bring the economy further away from its potential output and inflation.

These results point to the viability and great promise of using a behavioural macroeconomic model in place of the more traditional rational expectations one. Restating the expectations formation mechanism of standard macroeconomic models leads to a markedly different view of the economy as a complex system inhabited by heterogeneous agents trying to optimise in the face of radical uncertainty. Their moods and behaviour influence output and inflation realisations but are also influenced by them, thus introducing a complex feedback loop from subjective sentiments to objective dynamics. While this more complex formulation does not have a general analytic solution, it can be solved numerically for the purposes of forecasting and policy analysis.

One possible approach to modelling the system is through a calibrated model run over numerous periods, which allows forecasting both the point estimate and the confidence intervals of output and inflation realisations. The confidence intervals are much wider than the rational expectations model, thus reflecting the innate uncertainty of the economic system and clearly outlining the difficulties in successfully conducting monetary policy. Modelling the economy under the heterogeneous expectations assumption with a mechanism for modelling herding behaviour provides for a richer understanding of the processes at work and better empirical performance, but also outlines the limitations of trying to predict such a complex system with compact models.

The main limitations of the model under study lay in two directions. First, despite it being closer to modelling the amplitude of price fluctuations than the benchmark model, it still tended to underestimate them. Second, the data on the EU inflation were significantly skewed to the right, following an approximately lognormal distribution. This shows the tendency of prices to be sticky on the downside, and was not captured by either the RatExp or the HetExp model. These two directions of model improvement are the possible avenues of future research that can further improve the heterogeneous expectations model, making it an even closer approximation to actual economic dynamics.

6. Conclusion

Advances in behavioural economics show that individual economic agents make decisions and take action frequently on the basis of simple rules – or heuristics – that can override rationality. These insights can be used to supplement traditional macroeconomic models, thus providing for a much richer understanding of economic dynamics. This article added two important expectations formation heuristics on top of the rational expectations one – relying on the past (adaptive expectations) and relying on the 'wisdom of the crowd' (herding behaviour). Aggregate price expectations are thus a weighted average of the agents that use such heuristics, and those aggregates are the ones to influence realised inflation levels. The study demonstrated how to apply this approach within a simple DSGE model which illustrates that the heterogeneous expectations economy is much more volatile that the rational expectations one. In a sense, the RatEx economy cannot generate a business cycle on its own, which is mostly due to a predefined structure of exogenous shocks, and when a contraction occurs it is a particularly mild one.

In contrast, an economy with heterogeneous expectations does generate business cycles of its own. A small change in the balance of rational against adaptive agents is greatly magnified by herding, thus quickly shifting the way aggregate expectations are formed. As they drift away from rationality, the economy moves away from its potential output, and extreme inflation episodes ensue. This phenomenon proceeds along the lines of a self-fulfilling prophecy triggered by a small change in initial conditions. As agents become increasingly less rational in the sense of traditional neoclassical theory, the economy shifts away from its steady state, and thus their expectations that the economy will not be at its steady state are confirmed, leading to ever greater deviations. Thus, the incorporation of expectations heuristic in the model economy enables it to capture a key feature of real-life economic systems – the persistent and repetitive business cycles.

The addition of an alternative expectations formation mechanism complementing the traditional rational or adaptive expectations ones must also be borne out in empirical data. To test the actual importance of inflation expectations on realised price dynamics, the study investigated a panel of EU countries with monthly data spanning over twenty-two years. There was a high and statistically significant correlation between expectations of future inflation and current levels of inflation, as well as between perceptions of past inflation and current realizations, indicating that different types of expectations, namely forward and backward-looking, influence price dynamics, confirming the importance of modelling expectations as heterogeneous. There was a robust cointegration relationship between current month-on-month rise in HICP and a variety of expectation proxies – from consumer sentiments and overall economic conditions, to prices. This shows the tendency of agents to bundle together a wide variety of information to reach their conclusions, stressing again that simple heuristics were likely in use.

The introduction of herding into the model is driven by previous insights in the literature, but it is also crucial to accelerate the switch between rational and less rational regimes in the economy, and thus to enable the model to better emulate the observed empirical data in the EU. It is through herding that the heterogeneous expectations model is able to produce price fluctuations that are qualitatively similar to the ones observed in the empirical data. In this respect a model which is purely driven by rational expectations fails – the price volatility is not close to the actual one even at a first approximation. This leads to the conclusion that a behaviourally-informed model with heuristic-based expectations may be a better approach to simulate the economy. The specification may be close to the one presented in this study, or an alternative one that still captures the main insights from research in experimental macroeconomics. Therefore, it would seem imperative to complement current mainstream modelling with more psychological insights on the microfoundations of agent behaviour if a model is to ever approximate the workings of the actual economy.

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Appendix A

Table A1. Results of Johansen cointegration test with realised inflation month-on-month in previous year per country

Country	Consumer confidence	Economic situation, next 12m	Economic situation, previous 12m	Inflation expectations, next 12m	Inflation expectations, previous 12m
Austria	25.24	25.58	9.27	31.87	10.39
Belgium	23.46	28.72	10.69	23.67	14.33
Bulgaria	19.29	15.09	8.14	23.84	24.23
Croatia	9.01	16.65	4.66	14.00	6.44
Cyprus	10.87	16.79	6.80	14.28	19.91
Czechia	7.64	13.85	5.67	31.29	8.89
Denmark	26.06	22.66	16.78	32.65	6.84
Estonia	12.37	14.16	16.59	15.90	6.01
EU	21.87	25.92	10.98	20.12	4.92
Eurozone	21.52	28.21	9.85	16.79	7.11
Finland	33.54	23.48	20.36	27.17	11.49
France	17.97	24.95	12.87	23.37	14.34
Germany	12.27	20.23	5.11	12.18	7.88
Greece	6.59	10.75	5.68	26.17	11.73
Hungary	5.49	14.53	6.50	6.87	3.64
Ireland	7.88	13.47	6.52	28.11	34.22
Italy	12.39	23.49	14.57	23.57	14.46

Country	Consumer confidence	Economic situation, next 12m	Economic situation, previous 12m	Inflation expectations, next 12m	Inflation expectations, previous 12m
Latvia	11.95	9.50	13.80	24.20	13.50
Lithuania	16.62	20.49	14.84	17.74	4.85
Luxembourg	21.51	20.16	8.65	15.13	23.19
Malta	8.95	11.94	5.57	6.67	12.27
Netherlands	14.55	16.40	12.48	16.16	11.66
Poland	16.96	16.53	9.33	12.50	4.56
Portugal	10.73	12.32	6.21	24.63	13.03
Romania	27.96	27.99	29.87	36.07	46.68
Slovakia	13.19	18.37	11.07	34.27	21.07
Slovenia	11.21	11.81	4.04	19.92	12.62
Spain	11.60	17.84	6.90	16.20	22.26
Sweden	20.96	11.62	18.63	21.60	16.16
United Kingdom	12.06	9.42	5.72	10.50	12.42

Source: author's calculations.

Table A2. Results of Johansen cointegration test with realised inflation month-on-month in current year per country

Country	Consumer confidence	Economic situation, next 12m	Economic situation, previous 12m	Inflation expectations, next 12m	Inflation expectations, previous 12m
Austria	155.27	146.83	149.17	174.95	187.22
Belgium	184.65	178.40	171.94	183.42	200.09
Bulgaria	64.01	61.27	61.46	62.98	85.46
Croatia	46.25	45.66	48.21	57.86	75.43
Cyprus	96.71	96.45	97.09	101.04	101.34
Czechia	73.67	83.90	77.92	89.08	105.25
Denmark	123.41	116.01	111.01	108.80	163.45
Estonia	53.11	56.10	57.60	53.41	76.63
EU	103.39	102.28	103.28	111.41	139.39
Eurozone	122.57	120.52	123.63	130.30	156.98
Finland	104.48	99.13	93.89	107.71	122.10
France	106.58	105.51	105.44	114.95	130.65
Germany	82.27	79.22	80.04	87.34	101.33
Greece	191.80	187.29	184.38	193.97	196.13
Hungary	48.29	51.42	50.09	51.85	61.30
Ireland	83.44	80.27	80.95	108.44	133.56
Italy	188.34	191.45	194.18	194.79	208.84
Latvia	47.33	47.77	48.09	63.31	66.58
Lithuania	60.09	59.60	64.13	61.63	83.50
Luxembourg	127.95	119.87	118.90	130.90	157.46
Malta	43.98	43.89	44.26	44.79	44.72
Netherlands	126.90	122.68	122.75	122.85	137.93
Poland	49.60	57.13	52.82	68.78	81.33
Portugal	136.16	136.46	144.33	148.57	149.93
Romania	31.54	33.03	32.25	43.94	53.77
Slovakia	110.05	109.43	108.27	134.82	162.32
Slovenia	106.81	104.25	103.02	127.75	126.46
Spain	164.36	163.02	162.86	165.85	174.68
Sweden	140.28	123.49	126.18	115.18	188.62
United Kingdom	116.94	113.81	116.82	123.57	168.66

Source: author's calculations.