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3 September 2015

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Abstract

Standard dynamic stochastic general equilibrium (DSGE) models are populated by fully-informed-optimising Muth-rational agents. This kind of agent is at odds with well-known psychological biases, not to mention real life people. In particular, there are strong theoretical and empirical reasons to believe that consumers are overly optimistic. Also, the size of over optimism is likely to show cyclical features. In this paper we simulate two DSGE models, one standard with Muth-rational consumers, the other different just because agents are allowed to over consume. We then compare them throughout different cyclical phases. Results show that taking into account psychological biases allows the DSGE to fit better actual data in the long-run and in an economic boom scenario. Recessions are instead characterized by pessimism.

We also find that over consumption is a structural trait. Moreover, booms enlarge significantly the magnitude of the bias. These findings are in line with - and enrich - both the economic and psychological literature, implying i) that the business cycle has a non trivial psychological content, and ii) that the size of psychological biases is affected by macroeconomic evolutions.

JEL code: C30, D58, D80.

PsycINFO Classification code: 2340 Cognitive Processes.

Keywords: DSGE models, Psychological Biases, Business Cycle.

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1 Introduction

Standard DSGE are small-scale models formally analyzing an economic system. DSGE proponents assume that the system is populated by a representative utility-maximizing Muthian agent which operates subject to budget constraints and technological restrictions. Over time these models have become widespread and commonly used because they are a powerful tool that provide a coherent framework for policy discussion and economic analysis. In principle, they can help to identify sources of fluctuations, answer questions about structural changes, forecast the effect of policy changes, etc. Despite its widespread use, it has long been known that the conditions behind standard DSGE models are rather stringent. The rational expectations hypothesis is among them. On the theoretical side, Muth-rationality has been questioned by very many authors. Just to mention, the adaptive learning literature (Evans and Honkapohja, 2001) argues that individuals must relentlessly "learn" to try to be Muth-rational.

In their theory of heuristics and biases Kahneman and Tversky (1973, 1974, and 1982) - and their numerous followers - have convincingly suggested that intuitive strategies and simple heuristics are reasonably effective some of the time, but they also produce biases and give rise to systematic incongruities that are at odds with rational expectations.

In our setting it is worth noticing that psychologists rarely give indications about the size of these biases. On the empirical side, DSGE models still need to prove their ability to fit the data, especially in extraordinary cyclical phases. Since the last financial crisis and the subsequent great recession, indeed, a number of dissenting views have appeared in the literature (Manski, 2010; Caballero, 2010; Pesaran and Smith, 2011). As per psychological distortions Bovi (2009) reports evidence on the enduring presence of these biases throughout two decades and several European countries.

In particular, data confirm that people tend to form systematically over optimistic - with respect to Muth rationality - predictions. As per the typically maintained rational expectations hypothesis behind the DSGE models, two important points must be noted.

First, the mentoined biases are not transitory. Second they likely affect the majority of individuals and, therefore, even the representative agent operating in DSGE models.

It is unsurprisingly, then, that recently some economists have been inserting psychological issues - in particular overconfidence and overly optimism - within the framework of DSGE models. Some instances are the following. Farmer (2010) has estimated and compared two DSGE Keynesian models. The “old-Keynesian” differs from the “new-Keynesian” model because its Phillips curve is replaced with a belief function to determine expectations of nominal income growth. Data show that the old-Keynesian model fits the data better than its new-Keynesian competitor. Jaimovich and Rebelo (2006) have found that overconfidence can increase business cycle volatility. In addition, they have argued that optimistic agents expect an unrealistically high average rate of investment-specific technical change, and so they consistently overinvest. Milani (2011) has estimated a DSGE model relaxing the rational expectations assumption to evaluate the empirical role of expectational shocks on business cycle fluctuations.

The foregoing motivates our paper. Allowing over consumption in an otherwise standard DSGE setting we are able to shed some light on the above mentioned psychological and economic literature. On the one side, we can afford to quantify the size of psycho-induced over consumption both in the ”long run” and during different cyclical phases. On the other side, we can test whether the fitness of a psycho-biases augmented (PBA) DSGE model dominates that of a standard rational expectations (RE) DSGE one.

The analysis of different business cycle phases is particularly important here. In fact, one can expect that the effect of psychological factors could be magnified when the economy is improving.

Short-run self-fulfilling expectations and hedge behavior may play a role especially in booms (e.g., Farmer, 2010). By the same token, one can expect that amid recessions over consumption could be lowered both because of objective and of psychological reasons. As per the former, i) in crisis the cost of erring is higher and ii) the cost of information is lower. Think about the strong media coverage during economic crises (Curtin, 2003; Doms and Morin, 2004). As per the latter, the theory of depressive realism argues that depressed people tend to be more realistic than ”normal” individuals. Alloy and Abramson (1979) and followers (for a review, see Abramson et al., 2002) have pointed out that nondepressed people are more likely than depressed people to think that outcomes are contingent on their actions when they are not. They concluded that as opposed to demoralized persons, whose perceptions are apparently accurate, normal people distort reality in an optimistic fashion.The point is that the number of discouraged people is negatively correlated with the GDP growth rate.

It is important to note that our setting also allows examining how macroeconomic evolutions affect over consumption. This reverse engineering the viewpoint maintained by the macroeconomic literature, whereas psychological factors are inserted in macromodels to understand the business cycle.

Results show that nesting psycho-biases into a mainstream DSGE model improves the fitness of this latter in all the cyclical phases.

It turns out that, as argued by psychology, over consumption is a structural trait.

We also find that the magnitude of the distortion is significantly positive and larger during booms with respect to crises (to the extent that booms can be seen as "gains", our evidence is also somewhat in line with the theory of prospect).

Again, these findings support our hypotheses about the peculiar links between psycho-biases and consumption.

All in all, thus, our evidence supports the psycho-induced nature of the over consumption featuring the data.

The paper is organised as follows.

In the next section we describe the theoretical model from which our analysis begins, in section 3 we discuss the overconfindence hypothesis and how it may be inserted in a standard DSGE model. In section 4, we describe the empirical data used in our study and the methodology employed to estimate the parameters. In section 5, we analyse the model's dynamics through the impulse response functions and we compare the performance of the different model's specification through the measures of entropy. In section 6, we conclude.

2 The Theoretical Model

Dynamic stochastic general equilibrium models are built on microeconomic foundations and emphasize the rational agents' intertemporal choices. DSGE models are usually organised in three separate but interrelated blocks each modelling the behavior of three representative agents, namely the household, the firm and the policymaker.

The general equilibrium nature of the model captures the interaction between policy actions and agents' behavior. The dependence of current choices on future uncertain outcomes makes the model dynamic and assigns a central role to agents' expectations in the determination of current macroeconomic outcomes. Therefore, e.g., output and inflation tomorrow, and thus their expectations as of today, depend on monetary policy tomorrow in the same way as they do today; of course, taking into account what will happen from then on into the infinite future. The explanation so far refers to the equilibrium aspect of the model. The stochastic nature of the DSGE model allows out-of-equilibrium realizations. Every period random exogenous events perturb the equilibrium conditions, injecting uncertainty in the evolution of the economy and thus generating economic fluctuations. Without these shocks, the economy would evolve along a perfectly predictable path, with neither booms nor recessions. Markup shocks, for example, affect the pricing decisions of the firm that underlies the supply block, while demand shocks capture changes in the willingness of households to purchase the goods produced by the firm.

More specifically, ours is a standard three-blocks new-Keynesian closed economy DSGE model with rational expectations. The demand block captures the representative household's behavior, the supply block models the representative firm's decisions. In the policy block the key policy variable is the interest rate to reflect the tendency of central banks to raise the short-term interest rate when the economy is overheating as well as when inflation rises, and to lower it in the presence of economic slack. By adjusting the nominal interest rate, monetary policy in turn affects real activity and through it inflation, and eventually the effect acts on the supply block. The policy rule therefore closes the circle, giving us a complete model of the relationship between three key endogenous variables: real output, inflation, and the nominal interest rate.

Clearly, there are several potential candidates for our goals. However, the selected framework is representative of a larger class of models and it is commonly used in both macroeconomic practice and literature. Thus, the version we propose is the result of several validations and refinements. Our benchmark model is rich enough to provide a satisfactory empirical account of the evolution of output, inflation, and interest rate. All in all, the chosen model is a suitable and robust benchmark for our aims.

We are now ready to present more formally our benchmark model (for details, see Galí, 2003 and 2008, Smets and Wouters, 2003 and Galì and Monacelli, 2008). All the variables are expressed in log-deviations from their steady state values:

$$\begin{cases} y_t = (1-\lambda)\, c_t + \lambda g_t \\ \widetilde{y}_t = y_t - y_t^n \\ y_t^n = a_t \\ \pi_t = \beta \pi_{t+1}^e + \frac{(1-\theta)(1-\beta\theta)}{\theta} mc_t \\ mc_t = w_t - a_t \\ c_t = \left(\frac{\alpha}{1+\alpha}\right) c_{t-1} + (\frac{1}{1+\alpha}) c_{t+1}^e - \left(\frac{1-\alpha}{1+\alpha}\right) * (r_t - \pi_{t+1}^e) \\ w_t = \left(\frac{1}{1-\alpha}\right) c_t + \gamma n_t - \left(\frac{\alpha}{1-\alpha}\right) c_{t-1} \\ n_t = y_t - a_t \\ r_t = \phi_\pi \pi_t + \phi_y \widetilde{y}_t \\ a_t = \rho a_{t-1} + \epsilon_t^a \\ g_t = \varphi g_{t-1} + \epsilon_t^g \end{cases} \quad (1)$$

The subscript t means *at time* t, y is current output, $\widetilde{y}$ is the output gap, y^n is the fully-flexible price output, r is the nominal interest rate, π is the inflation rate, g is the public expenditure, mc denotes the real marginal cost of firms, w are real wages, a is the labor productivity, n is labor and x_{t+1}^e denotes the rational expectation of variable x at time $t+1$ formed at time t. The last two equations determine the stochastic dynamics of the labor productivity and public expenditure. The stochastic perturbations ϵ^a and ϵ^g are I.I.D.

Table 1 collects and describes the economic meaning of the parameters of our model.

Table 1: Definition of the model parameters

λ	steady state government spending share
α	persistence in private consumption
ρ	persistence of public expenditure
φ	persistence of labor productivity
β	rate of time preference
θ	index of price rigidity
γ	intertemporal elasticity of substitution for leisure (Frisch elasticity)
ϕ_π	sensitivity of central bankers to inflation
ϕ_y	sensitivity of central bankers to cyclical stances

3 Nesting Psychology in the DSGE Model

In this section we emphasise the reasons why it may be useful to take into account the possibility that agents may follow biased - with respect to Muth-optimal ones - consumption paths. Specifically, we will argue that this structural bias should be strictly positive and that it should increase with GDP growth.

It is also important to note that the following argumentation allows drawning the set of the hypotheses to be tested in this paper.

It is well-known that most people are overconfident about their own relative abilities, and unreasonably optimistic about their future (see, e.g., Camerer and Lovallo, 1999). As Kahneman put it: "The bottom line is that all the biases in judgment that have been identified [by psychologists] in the last fifteen years tend to bias decision-making toward the hawkish side."[1]

Similarly, Shiller (2000, page 142) has argued that "Yet some basic tendency towards overconfidence appears to be a robust human character trait: the bias is definitely toward overconfidence rather than underconfidence." Bovi (2009) reports evidence on the enduring presence of psychological biases throughout two decades and several European countries.

In particular, data confirm that European citizens tend to be systematically overly bullish. There are also papers testing the presence and examining the

[1] This quotation is reported in Johnson et al. (2006).

effects of overconfidence - Koellinger et al. (2007), Abreu and Mendes (2012), Fellner and Krugel (2012). Although we are aware of the difference between them[2], in the present setting we consider over-optimism and overconfidence as equivalent terms in the sense that both generate the bias that we want to add to our PBA DSGE model. In fact, several authors show that these two biases tend to go hand-in-hand. Kahneman and Tversky (1979a, 1979b) demonstrate that human judgment is generally optimistic due to overconfidence. Montier (2007) concludes the over-optimism and overconfidence tend to have the same causes - the illusion of control and the illusion of knowledge. Brunnermeier and Parker (2005) have then argued that, in a consumption-saving example, consumers are both overconfident and over-optimistic. Baker and Nofsinger (2010) offer a recent survey reinforcing the point. Coming back to our main point, the foregoing suggests that there are strong theorical and empirical reasons to think that the majority of people is overly optimistic and may be induced to over consume. Thus, in the empirical part of the paper we hypothesise that the representative agent populating DSGE models should be allowed to consume differently from Muth-rationality. It may be useful here to recall Brunnermeier and Parker's argument on over optimism (2005). Their conclusions on over optimism are based on the assumption that people maximize average felicity, optimally balancing this benefit of optimism against the costs of worse decision making. Otherwise stated, they examine distorted expectations while maintaining that agents optimize knowing the correct mapping from actions to payoffs in different states of the world.

We draw more deeply from psychology - our agents are over optimists not because it is rationale to do that. Their decisions are biased because of a number of unavoidable psychological reasons (one would say "deep" reasons, following the mainstream economics jargon). We assume that because psychologists convincingly suggest that people use rules of thumb with no sign that they learn or are totally aware of the cost of their decisions (Bovi, 2009). This notwithstanding, we share with Brunnermeier and Parker's setting the crucial fact that, when psychological stimuli are taken into account, over consumption emerges

[2] The expectations of optimistic agents are biased toward good outcomes, while overconfident agents overestimate the precision of the signals that they receive.

as a structural feature of agents' decision making. Though, as said, over consumption is likely to be a structural trait of the human behavior, it can also be conceptualised that the bias reacts to cyclical phases in a predictable way. It let us to test another two assumptions, offering even more discipline to our exercise. During goldilocks periods, indeed, there can emerge a tendency to be even more optimistic than usual. Given the structural over optimism, in fact, self fulfilling expectations may emerge especially during booms (Farmer, 2010), in that creating the tendency for being even more bullish. In addition, this could trigger herd behaviors whereas even less optimistic agents over consume (Milani, 2011; De Grauwe, 2012). Using the famous Mr. Greenspan's words, "irrational exuberance" is at work (see also Shiller, 2000). The rationale for over consumption to be lower amid crises can be described as follows. Both economic and psychological elements play a role (Bovi, 2009). As per the former, in bad times the cost to err is higher while the cost of information is lower. Think about the strong media coverage during economic crises (Curtin, 2003; Doms and Morin, 2004). Thus, there are both more motivations and more occasions to act as a "muthian". In fact, given bounded rationality and the like, to try to act as muthians. As per the latter, the theory of the depressive realism (for a review, see Abramson et al., 2002) convincingly argues that discouraged people are less decoupled from reality than "normal" individuals.

The point is that the share of sadden individuals obviously increases in economic turmoil. Note that the theory of the depressive realism is coherent with the theories supporting the structural - i.e. "normal" - over optimism: typically the majority of people is not demoralized. As mentioned, we are interested in testing whether psycho-biases affect and are affected by macroeconomic evolutions. Our definition of psycho-bias is accordingly very general such that to include all the systematic psycho-driven consumption that may explain that part of the business cycle which is typically left unexplained by mainstream rational expectations DSGE models.

In order to introduce the agents' over consumption into the rational expectations model in (1), this latter needs to be rearranged.

One simple and effective way to do so is to add to the standard consumption function an element allowing households to follow both Muth-rational and biased behaviors.

More specifically and formally, the psycho-biased augmented (PBA) new-Keynesian model we refer to is equal to (1), but for the fact that in the Euler equation modeling

the private consumption, c_t, we insert the expected component, c_t^e:

- *Rational expectations (RE) - benchmark:* Model (1) with

$$c_t = \left(\frac{\alpha}{1+\alpha}\right) c_{t-1} + (\frac{1}{1+\alpha})c_{t+1}^e - \left(\frac{1-\alpha}{1+\alpha}\right) * (r_t - \pi_{t+1}^e)$$

- *Psychological biases (PBA):* Model (1) with $\delta > 0$

$$c_t = \left(\frac{\alpha}{1+\alpha}\right) c_{t-1} + (\frac{1}{1+\alpha})c_{t+1}^e + \delta \left|c_{t+1}^e\right| - \left(\frac{1-\alpha}{1+\alpha}\right) * (r_t - \pi_{t+1}^e)$$

It should be clear that the rationale for this new element derives from the previous discussion about the representative individual tendency toward over consumption. Specifically, note that we plug the bias using the module of the expected consumption times delta. The logic for that is that our key parameter is delta, which we assume to be greater than zero - the module ensures us that a positive sign of delta implies over consumption. However, in simulations we allow delta to assume even negative or zero values. By letting the data speak we can thus obtain more robust evidence.

It may also be added that just as the theorised presence of habits justifies the presence of the lagged consumption in the Euler equation, the theorised presence of psycho-biases justifies the presence of the expected consumption in the Euler equation. Last but not least, note that the PBA model generalises the RE one - by construction when $\delta = 0$ they are equal.

Given our goal, we examine the two models under different circumstances:

- whole sample (the "long run");
- subsample of economic booms;
- subsample of economic recessions[3];

[3] In this framework an economic boom is defined a context in the presence of a positive cyclical output growth, i.e. $\Delta \ln Y_t > 0$, whereas an economic recession occurs whenever $\Delta \ln Y_t < 0$.

The first exercise allows gathering information on the size of the structural over consumption, the other two exercises aim at shedding some light on the cyclical behavior of over consumption. Altogether they provide a suitable framework to test our hypotheses and the necessary information to address our research goals.

4 Data and Estimation methodology

The inferential methodology adopted to estiamte the model parameters, to simulate and analyze the dynamic behavior of the relevant variables is based on Monte Carlo Markow Chains (MCMC) algorithm, that belongs to the family of Bayesian estimation. We build a multi-chain MCMC procedure based on 4 chains of size 100,00; the algorith converges within 55,000 iterations to its corrected expected value, and, according to these results, we discard the first 55,000 draws from each chain to remove any dependence from the initial conditions.

In detail, our estimation procedure is based on two steps. In the first step, we estimate the mode of the posterior distribution by maximizing the log posterior density function, which is a combination of the prior information on the structural parameters with the likelihood of the data. In the second step, we use the Metropolis-Hastings algorithm in order to draw a complete picture of the posterior distribution and compute the log marginal likelihood of the model. The convergence diagnostic is based on Brooks and Gelman (1998) method.

All of the model computations have been performed using DYNARE software[4]. Below, we summarize the measurement equations considered, i.e. the relationships between the model variables (on the right side) and the data (on the left side):

$$\begin{bmatrix} \Delta \ln P_t \\ \Delta \ln Y_t \end{bmatrix} = \begin{bmatrix} \overline{\pi} \\ \overline{\eta} \end{bmatrix} + 100 * \begin{bmatrix} \pi_t \\ y_t - y_{t-1} \end{bmatrix} \tag{2}$$

where $\Delta \ln X_t$ stands for $100 * (\ln X_t - \ln X_{t-1})$, P_t is the personal consumption expenditures' price index, Y_t is the real GDP, $\overline{\eta} = 100 * (\eta - 1)$ is the real GDP quarterly trend growth rate and $\overline{\pi} = 100 * (\Pi^* - 1)$ is the quarterly steady-

[4]Dynare is a software that is freely available from the website http://www.dynare.org and has the ability to simulate and estimate economic models

state inflation rate. The dataset consists of quarterly data for real GDP and personal consumption expenditures' price referring to the US from 1959q2:2014q1. The source of the data is Federal Reserve Economic Data (FRED).

Following the logic of this paper, we have used standard values and distributions (see Table 2) for the prior densities of the parameters of the system (1) as suggested by the literature. In particular, we have adopted the mean values, the standard deviations and distributions reported in Smets and Wouters (2007) for the parameters related to the utility function and monetary policy, whereas we have followed real business cycle literature (King and Rebelo, 1999) and Smets and Wouters (2003) for the high persistence in labor productivity and public expenditure. The prior mean value for the steady state government spending share is the average ratio between US real public expenditure and real GDP from 1959q2:2014q1.

In the following table, we compare prior and posterior ditributions of the parameters in the absence of psycho-bias, i.e. $\delta = 0$:

Table 2: **Prior and Posterior Distribution of Structural Parameters: the benchmark case**

Parameter	Prior distribution			Post. distribution		
	Distr.	Mean	St. Dev.	Mode	Mean	Conf. Interval 95%
α	beta	0.75	0.05	0.77	0.77	[0.7636 0.7689]
β	beta	0.90	0.10	0.88	0.88	[0.8763 0.8806]
γ	gamma	2.00	0.75	2.04	2.03	[1.9987 2.0559]
ϕ_π	normal	1.50	0.25	1.47	1.47	[1.4586 1.4866]
ϕ_y	normal	0.125	0.05	0.00	0.005	[0.0028 0.0077]
ρ	beta	0.975	0.10	1.00	0.999	[0.9971 1.0000]
φ	beta	0.90	0.05	0.97	0.973	[0.9723 0.9738]
λ	beta	0.26	0.05	0.22	0.22	[0.2121 0.2273]
$\overline{\pi}$	gamma	0.83	0.10	0.68	0.83	[0.6716 0.6836]
$\overline{\eta}$	normal	0.76	0.10	0.77	0.78	[0.7749 0.7792]
θ	beta	0.75	0.10	0.83	0.83	[0.8222 0.8327]
σ_{ϵ^a}	inv.gamma	0.10	2.00	0.02	0.02	[0.0176 0.0189]
σ_{ϵ^g}	inv.gamma	0.10	2.00	0.04	0.04	[0.0359 0.0381]

The posterior values are substantially in line with the prior ones except for the steady state share of public expenditure on GDP, the sensitivity of Central Bank to inflation, the standard errors of labor productivity and public expenditure processes, that exhibit a strong negative shift, and the index of price rigidity that has a positive shift.

The log-marginal value of the likelihood in this standard case, computed by Laplace approximation is -460.38.

In table 3, we show prior and posterior distributions of the parameters in the presence of psycho-bias; in this case, the Euler equation of (1) reads as

$$c_t = \left(\frac{\alpha}{1+\alpha}\right) c_{t-1} + (\frac{1}{1+\alpha}) c^e_{t+1} + \delta \left|c^e_{t+1}\right| - \left(\frac{1-\alpha}{1+\alpha}\right) * (r_t - \pi^e_{t+1})$$

The prior distribution of psycho-bias, δ, is assumed gamma with a mean close to zero and unitary standard error. This choice is driven by the over consumption hypothesis, implying positive values of δ; the almost zero-mean[5] hypothesis allows us to collapse the psycho-bias case to the benchmark one in expected value. Finally, the high value of the standard error does not bind the posterior value of δ in a narrow range:

The log-marginal value of the likelihood for this case is -417.74. In order to compare this scenario (δ) with the benchmark case (b) we build the Bayes factor through the Laplace method to approximate the integrated likelihood (Kass and Raftery, 1995 and Lewis and Raftery, 1997), that is:

$$B_{\delta,b} = 2 \ln \left[\frac{f\left(\mathbf{Y}|M_{PBA}\right)}{f\left(\mathbf{Y}|M_{RE}\right)}\right] \tag{3}$$

where

$$f\left(\mathbf{Y}|M_m\right) = \int f\left(\mathbf{Y}|\boldsymbol{\theta}_m, M_m\right) f\left(\boldsymbol{\theta}_m|M_m\right) d\boldsymbol{\theta}_m \quad m = PBA, RE \tag{4}$$

with M_{PBA} and M_{RE} indicating respectively the PBA model and RE model. The Bayes factor is equal to 85.28, that supports decisively the specification including the psycho-bias parameter. Hence, the PBA model is able to better capture the stylized facts concerning the business cycle.

The posterior value of the mode psycho-bias parameter δ is significantly

[5] Gamma distribution is not defined for a mean equal to 0, hence we choose a value close to zero but greater than it (0.01).

Table 3: **Prior and Posterior Distribution of Structural Parameters: the psycho-bias case**

Parameter	Prior distribution			Post. distribution		
	Distr.	Mean	St. Dev.	Mode	Mean	Conf. Interval 95%
α	beta	0.75	0.05	0.85	0.86	[0.8310 0.8735]
β	beta	0.90	0.10	1.00	0.97	[0.9458 1.0000]
γ	gamma	2.00	0.75	2.04	2.03	[1.8591 2.1629]
δ	gamma	0.01	1.00	0.33	0.32	[0.0100 0.5855]
ϕ_π	normal	1.50	0.25	1.39	1.38	[1.2856 1.4718]
ϕ_y	normal	0.125	0.05	0.00	0.0029	[0.0000 0.0063]
ρ	beta	0.975	0.10	1.00	0.999	[0.9957 1.0000]
φ	beta	0.90	0.05	0.96	0.96	[0.9498 0.9679]
λ	beta	0.26	0.05	0.28	0.28	[0.2443 0.3067]
$\overline{\pi}$	gamma	0.83	0.10	0.80	0.81	[0.7383 0.8724]
$\overline{\eta}$	normal	0.76	0.10	0.76	0.71	[0.6382 0.7778]
θ	beta	0.75	0.10	0.89	0.89	[0.8816 0.8972]
σ_{ϵ^a}	inv.gamma	0.10	2.50	0.03	0.03	[0.0218 0.0316]
σ_{ϵ^g}	inv.gamma	0.10	2.40	0.03	0.03	[0.0255 0.0325]

different from zero[6], thus confirming the empirical validity of the psycho-bias hypothesis in the Euler equation.

Furthermore, there is a positive shift of the intertemporal discount factor, β, that strengthens the over-confidence hypothesis regarding future consumption. The sensitivity of central bankers to cyclical stances is strongly reduced (from 0.125 to 0.001) and the sensitivity to inflation is slightly decreased. As in Smets and Wouters (2007), monetary policy appear to react less strongly to the output gap than to inflation as in the rational expectation case. Moreover, the consumption persistence parameter, α, is higher than the previous case, thus indicating greater adjustment costs in consumption between $t-1$ and t. The remaining posterior values of the parameters are quite similar to the benchmark

[6] In order to save space, we have not published the values of the posterior standard deviations, from which the statistical significance of the mode of parameters is derived. This piece of information is available upon request.

case.

In table 4, there is a comparison between prior and posterior distributions of the parameters for the subsample of economic boom. In this case the psycho-bias parameter δ is still significantly different from zero, but also greater than the "long run" case. The Frish elasticity of labor supply $\left(\frac{1}{\gamma}\right)$ exhibits a positive shift, that indicates more flexibility in the labor market in this business cycle phase, whereas price-rigidity, θ, is higher than the rational expectations and "long run" psycho-bias cases.

Table 4: **Prior and Posterior Distribution of Structural Parameters: the psycho-bias case with boom**

Parameter	Prior distribution			Post. distribution		
	Distr.	Mean	St. Dev.	Mode	Mean	Conf. Interval 95%
α	beta	0.75	0.05	0.72	0.75	[0.6927 0.8133]
β	beta	0.90	0.10	1.00	0.91	[0.7677 1.0000]
γ	gamma	2.00	0.75	1.96	1.73	[1.0996 2.5422]
δ	gamma	0.01	1.00	3.77	2.64	[0.0100 5.0156]
ϕ_π	normal	1.50	0.25	1.48	1.30	[1.0865 1.5993]
ϕ_y	normal	0.125	0.05	0.02	0.01	[0.0000 0.0131]
ρ	beta	0.975	0.10	0.79	0.85	[0.7689 0.9217]
φ	beta	0.90	0.05	0.96	0.97	[0.9495 0.9809]
λ	beta	0.26	0.05	0.34	0.21	[0.1225 0.3012]
$\overline{\pi}$	gamma	0.83	0.10	0.77	0.71	[0.6311 0.7862]
$\overline{\eta}$	normal	0.79	0.10	0.61	0.70	[0.5359 0.8289]
θ	beta	0.98	0.10	0.83	0.84	[0.7943 0.8975]
σ_{ϵ^a}	inv.gamma	0.10	3.60	0.02	0.04	[0.0219 0.0617]
σ_{ϵ^g}	inv.gamma	0.10	2.30	0.02	0.03	[0.0182 0.0427]

Also in this case the Bayes factor (equal to 60.92) corroborates the PBA model with respect to the RE one.

Finally, table 5 deals with the subsample of economic recession. The posterior value of the mode of δ in this case is not different from zero, thus rejecting the PBA model in this scenario. Indeed, this result is coherent with the empirical evidence found by Bovi (2009): in bad times over critical judgements about the economic conditions occur, due also to the influence of the media, and hence there is not any space for over confidence.

The worse performance of the PBA model compared to the RE one in a recessive phase of the business cycle is also confirmed by the Bayes factor (equal to -222.35) that strongly supports the Muth-rationality.

The intertemporal discount factor, β, in this case has a negative shift with respect to the prior mean, thus showing a smaller degree of preference for future consumption in the negative phases of the business cycle. The Frish elasticity of labor supply $\left(\frac{1}{\gamma}\right)$ decreases compared to the prior mean as is the case for the price rigidity index, θ. Furthermore, in this case the Taylor rule parameters exhibit a positive shift, thus showing that during recessions monetary policy overreacts both to inflation and output gap with respect to the standard case.

Table 5: **Prior and Posterior Distribution of Structural Parameters: the psycho-bias case with recession**

Parameter	Prior distribution			Post. distribution		
	Distr.	Mean	St. Dev.	Mode	Mean	Conf. Interval 95%
α	beta	0.75	0.05	0.76	0.77	[0.7650 0.7793]
β	beta	0.90	0.10	0.89	0.89	[0.8775 0.9030]
γ	gamma	2.00	0.75	2.11	2.12	[2.0063 2.3038]
δ	gamma	0.01	1.00	0.00	0.0058	[0.0000 0.0178]
ϕ_π	normal	1.50	0.25	1.54	1.52	[1.4856 1.5817]
ϕ_y	normal	0.125	0.05	0.14	0.13	[0.1230 0.1500]
ρ	beta	0.975	0.10	0.96	0.94	[0.9355 0.9510]
φ	beta	0.90	0.05	0.90	0.90	[0.8964 0.9090]
λ	beta	0.26	0.05	0.26	0.25	[0.2439 0.2677]
$\overline{\pi}$	gamma	1.13	0.10	1.15	1.16	[1.1523 1.1702]
$\overline{\eta}$	normal	-0.76	0.10	-0.73	-0.71	[-0.7338 -0.6943]
θ	beta	0.75	0.10	0.73	0.72	[0.7012 0.7352]
σ_{ϵ^a}	inv.gamma	0.10	2.80	0.03	0.02	[0.0176 0.0281]
σ_{ϵ^g}	inv.gamma	0.10	0.95	0.05	0.04	[0.0331 0.0524]

5 Results

5.1 The Model's Dynamics

In this section, we discuss the dynamic response of the relevant variables when the economy is hit by stochastic shocks on labor productivity and public expenditure, namely impulse response functions (IRFs).

Note that for all of the IRFs, the size of the standard deviations of the stochastic shocks and the variables' responses relate to the posterior-average of the IRFs for each draw of the MCMC algorithm, together with 95 percent confidence intervals[7]. Moreover, because the variables are expressed in logs, the measures of the responses can be read as elasticities.

In figures 1 and 2, we show the dynamic responses of the model's variables in the presence of a labor productivity and public expenditure shocks when $\delta = 0$ (absence of any psychological bias). Indeed this is a standard DSGE model with habit formation in consumption (Galí, 2003 and 2008, Smets and Wouters, 2003).

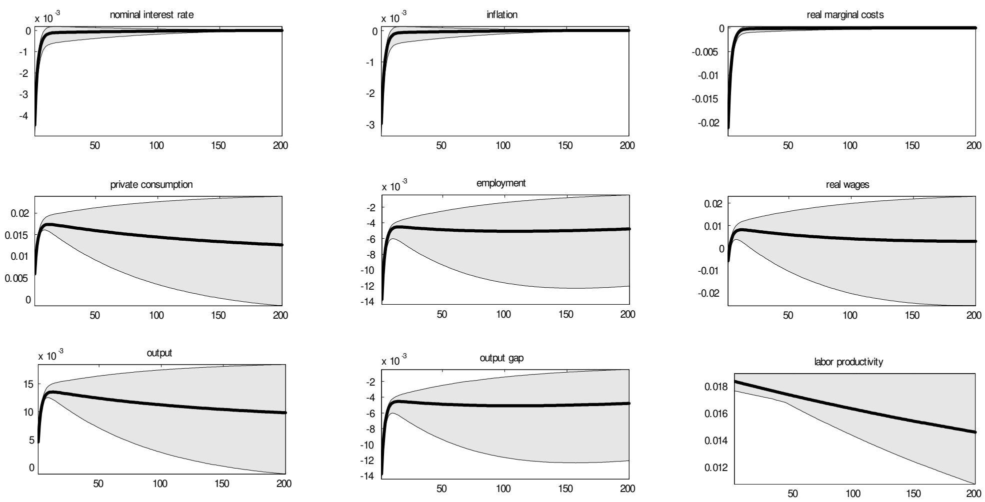

Figure 1: Impulse response functions for a positive labor productivity shock with $\delta = 0$

An increase in labor productivity generates a positive growth of actual out-

[7]The confidence intervals have been computed as the 2.5 and 97.5 percentiles of the empirical distributions obtained by the algorithm.

put and potential output; nevertheless, the latter increases by more than the former because of price stickiness (Calvo, 1983). In fact, this distorsion implies that only a fraction of producers lowers the prices when a positive supply shock hits the economy: hence, actual output does not grow in the same proportion of the shock because private consumption increases by less than the fully flexible price equilibrium. As a consequence of this, output gap decreases. The short term nominal interest rate reduces as a response of output gap and inflation diminishing. The increase in labor productivity generates a contraction in the real marginal costs, that are also decreased by a reduction in the real wages due to the fall in labor demand. In fact, as the empirical literature has widely shown (Christiano et al. 1992 and Galì 1999, among the others), actual output does not increase in the same proportion of the technology shock for the price rigidity and hence an employment reduction occurs.

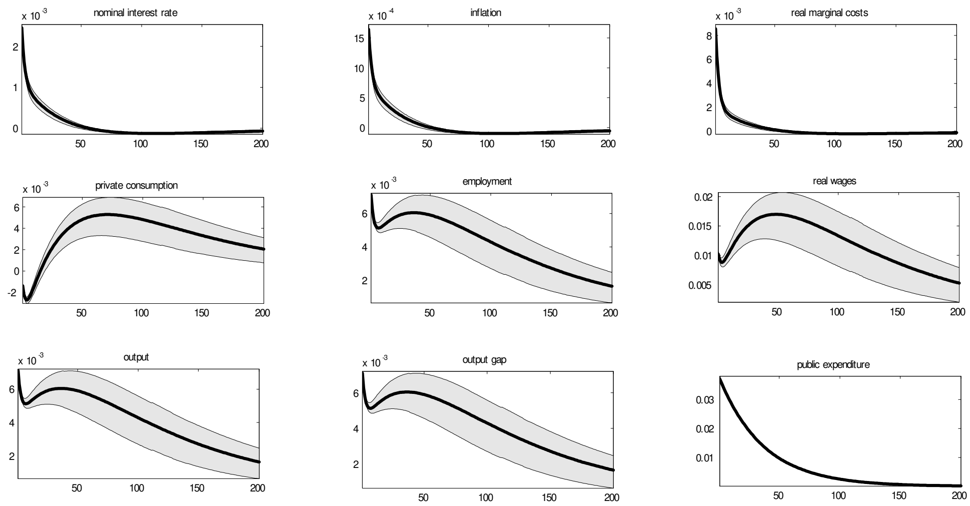

Figure 2: Impulse response functions for a positive public expenditure shock with $\delta = 0$

When a positive shock in public expenditure hits the economy, private consumption decreases due to a crowding out effect; the positive growth of actual output, pushed up by public sector demand, generates an increase in employment, in the real wages and so in the real marginal costs. These latter cause a rise in the inflation rate, but the presence of price stickiness reduces the impact of real marginal costs on inflation, thus generating a smaller increase in the inflation rate than the fully flexible price scenario. Therefore, the increase in the nominal interest rate resulting from the enhanced inflation is lower than in the absence of price stickiness. In this way the consequent crowding out effect is smaller than the case of fully flexible prices and then output gap increases.

When $\delta > 0$ (figure 3 and 4), IRFs are qualitatively similar to the case of rational expectations: the quantitative differences are linked to the different values resulting from the estimation process of the parameters:

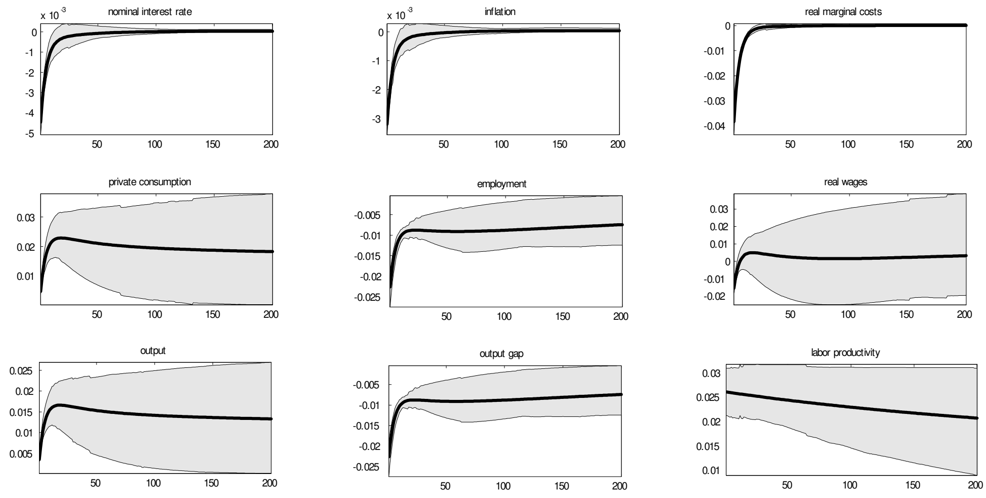

Figure 3: Impulse response functions for a positive labor productivity shock with $\delta > 0$

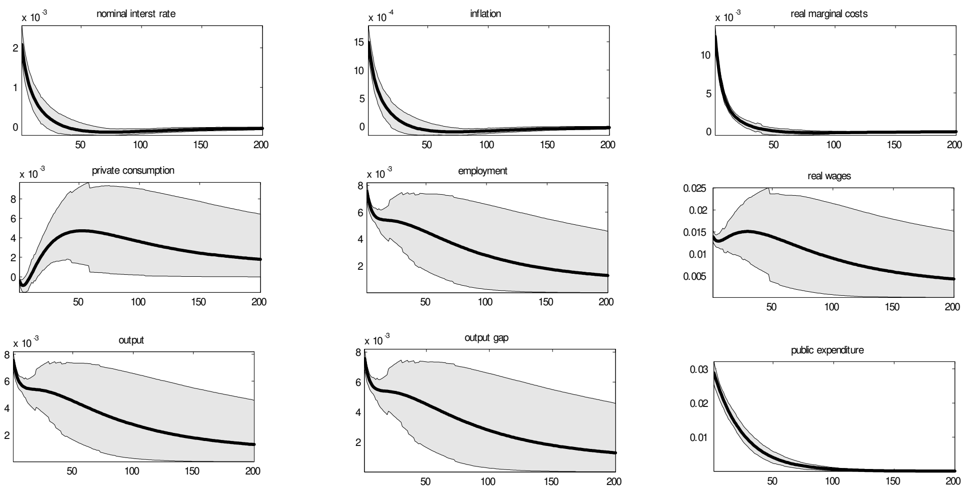

Figure 4: Impulse response functions for a positive public expenditure shock with $\delta > 0$

5.2 The Models' Performance

The comparison between the models is performed through measures of entropy. The idea is to measure how the models involved in the "race" fit actual data, analysing the *distance* between actual data of private consumption, and those stemming from simulating the two competitors. These measures are particularly appropriate for our purposes because they involve the *entire* empirical distribution of the data under scrutiny. Thus our measure encompasses all information provided by statistics like mean, variance, skewness, kurtosis, autocorrelations at different lags, and so on. This is different with respect to what typically done in the macroeconomic literature where the fitness of DSGE models is based on less general tools such as impulse response functions, standard deviations and correlations.

The simulated time series for the RE and PBA models are generated through the MCMC method over the 223 quarters represented in the sample for from 1959q2:2014q1. For each quarter, we draw 100,000 realizations of the stochastic shocks described and identified in Section 4. Next, we take the expected value of this sequence as the corresponding value for each quarter[8]. The peculiar measure of entropy we use can be briefly described as follows. If we consider a generic sample of real numbers $\{x_1, x_2, \ldots, x_N\}$, with $N \in \mathbb{N}$, the entropy is given by:

$$\mathcal{E} = \sum_{k=1}^{N} \frac{|x_k|}{\sum_{j=1}^{N} |x_j|} \cdot \log\left(\frac{|x_k|}{\sum_{j=1}^{N} |x_j|}\right) \tag{5}$$

Armed with this definition, we compute the *reference entropies*, i.e. those related to actual data. We denote $\mathcal{E}_c$ the reference entropy for consumption. Then, we calculate the entropies of the simulated series, for both the RE and the PBA model, as coming out from the estimation of the parameter δ. We denote them as $\mathcal{E}_c^{RE}$ (rational expectations) and $\mathcal{E}_c^{PBA}$ (psychological biases).

Clearly, in our context the sign of the distances does not matter. Therefore, the absolute value of the difference between the entropies referring to actual data and those referring to the RE model represents our three *benchmark distances*:

$$d_c^{RE} = |\mathcal{E}_c^{RE} - \mathcal{E}_c| \tag{6}$$

Similarly, we measure the distances between the entropy related to consumption in the cases of the PBA model and those related to actual data:

$$d_c^{\delta} = |\mathcal{E}_c^{PBA} - \mathcal{E}_c| \tag{7}$$

As it should be clear, the PBA model dominates the RE one if and only if

$$D_c^{\delta, RE} = d_c^{\delta} - d_c^{RE} < 0$$

The evaluation of the performance through entropies has been implemented for the overall sample of data:

Table 6 collects the findings, whereas in table 7 we report the differences in (6) and (7).

The empirical moments calculated on the simulated data show that for the whole sample, PBA model dominates the RE one for consumption and output data with a percentage relative improvement respectively of 15% and 30%.

In the sub-sample of boom, PBA model has a relative better performance than the RE one for inflation and output with a percentage relative improvement respectively of 19% and 4.6%.

[8] Hence, our estimate for each quarter is the average of all the trajectories obtained.

Real data	Consumption	Inflation	Output
ENTIRE SAMPLE	-5,22488144	-5,179040033	-5,197282252
SUB-SAMPLE OF BOOM	-5,099315553	-5,05401485	-5,069978629
SUB-SAMPLE OF RECESSION	-3,116948633	-3,146713182	-3,092239707
RE model	Consumption	Inflation	Output
ENTIRE SAMPLE	-5,139635847	-5,151989956	-5,09927735
SUB-SAMPLE OF BOOM	-4,553586321	-4,437539173	-4,458158037
SUB-SAMPLE OF RECESSION	-4,48189807	-4,463350478	-4,555663277
PBA model	Consumption	Inflation	Output
ENTIRE SAMPLE	-5,152276937	-5,080303923	-5,128233501
SUB-SAMPLE OF BOOM	-4,544375956	-4,556105382	-4,486054012
SUB-SAMPLE OF RECESSION	-4,433961315	-4,446918201	-0,0000000157775

Table 6: Entropies for private consumption. The analyzed case is the overall sample.

Finally, in the case of recession the slight betterment for consumption and inflation (3% for both the variables) of PBA model compared with RE one is accompanied by a strong worsening of the output of more than 300%. This evidence confirms the results of the Bayesian estimation process, stating that in a recessive phase of the business cycle individuals are not prone to over confindence.

6 Concluding Remarks

There are strong theoretical and empirical reasons to believe that real life consumers do not behave as the agent populating standard dynamic stochastic general equilibrium (DSGE) models. In particular, main street individuals are likely to over consume, in the sense that they follow consumptions path higher than those of Muth-agents. Alike, the size of over optimism is likely to show cyclical features. Borrowing from both the economic and psychologic literature we have pinned down some testable hypotheses - i) over consumption is a structural trait; ii) psychological biases tend to be magnified in booms. Thus, in this

RE model	Consumption	Inflation	Output
ENTIRE SAMPLE	0,085245592	0,027050076	0,098004902
SUB-SAMPLE OF BOOM	0,545729232	0,616475678	0,611820592
SUB-SAMPLE OF RECESSION	-1,364949437	-1,346401845	-1,438714644
PBA model	Consumption	Inflation	Output
ENTIRE SAMPLE	0,072604503	0,09873611	0,069048751
SUB-SAMPLE OF BOOM	0,554939597	0,497909468	0,583924617
SUB-SAMPLE OF RECESSION	-1,317012682	-1,30020502	3,092239691

Table 7: Differences between entropies in the RE and PBA cases and the benchmark case. Computations are obtained by using formulas (6) and (7) and the values reported in Table 6.

paper we have simulated two DSGE models, one standard with Muth-rational consumers, the other different just because agents are allowed to over consume. We have then compared them throughout different cyclical phases. Results have shown that taking into account over confidence and over optimism allows the DSGE to fit better actual data in the long run and for the expansionary phases of the business cycle. In recession, instead, individuals are more pessimist due also to the influence of the media.

We have also pointed out that over consumption is a structural trait. Moreover, booms turn out to enlarge significantly the magnitude of the bias. These empirical outcomes are in line with - and enrich - both the economic and psychological literature, implying i) that the business cycle has a non trivial psychological content, and ii) that the size of psychological biases is affected by macroeconomic evolutions.

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