



Escuela de Economía y Finanzas

# Documentos de trabajo

## Economía y Finanzas

Centro de Investigación  
Económicas y Financieras

**No. 16-01** **A contribution of Bayesian approach to**  
**2016** **experimental economics**

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# A contribution of Bayesian approach to experimental economics.\*

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February 2, 2016

## Abstract

The main contribution of this work is the discussion about the widespread of the data from the economic experiments. Particularly, in regards with those that research about the discounting rate of the agents, where we suggest using the Dynamic Stochastic General Equilibrium models (DSGE) under a Bayesian approach. Besides, the inclusion of the entrepreneurs in the economic experiments in order to establish which are the long and short discounting rate is also mentioned. In this way, in order to reach what was said before, both a Neoclassic and a Neo Keynesian standard model were used to contrast the parameters robustness. Finally, it is showed that both the short and long term discounting rates after using Bayesian estimation are more consistent with the experiments carried out with entrepreneurs than those with students.

JEL Classification: E37, D91, E32

Keywords: Models and applications, Intertemporal Consumer Choice, Bayesian econometrics.

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\*We thank to Fernando Tohmé and Germán Gonzalez for fruitful comments and discussions. Also, we thank the EAFIT University for supporting the project. All remaining errors are our own.

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# 1 Introduction

The main contribution of this paper is to discuss a little bit more about the estimates of the discounting rate by comparing the experimental economics with the Dynamic Stochastic General Equilibrium models (DSGE) under Bayesian approach. To reach this, two different elements from other works that investigate about the discounting rate of the agents will be used. Regarding the first element, it is the fact of highlighting the importance of who is going to be the subject of the experiment, in this case, the experimental study carried out with entrepreneurs. To achieve this, it was set a comparison of economic experiments done in Colombia; one of those to university students (Wang, Rieger, and Hens, 2010) and the other to entrepreneurs (Hurtado Rendón, 2014a). Regarding the latter one, entrepreneurs were chosen since those are the ones that make the decisions on how much capital utilize. In this manner, that is why the entrepreneur decides indirectly on intertemporal consumptions of the economy. Second, it is the fact of using the Bayesian estimation in order to make a comparison of the results of the experiments by selecting which of the economic experiments is more applicable to a particular economy in order to finally widespread the results from this and ahead.

Since Samuelson (1937) proposed the exponential discounting rate, it was necessary the use of this concept. Nonetheless, Strotz (1956) used the hyperbolic discounting rate based on the fact that people are more impatient in the short term rather than in the long term. In other words, people present problems of dynamic inconsistency, which is the main reason why people do not achieve their initial plans. Thus, a series of authors agree on the fact that the agents discount a hyperbolic discounting rate, as it was stated by Loewenstein and Prelec (1992), Herrnstein (1981) and Harvey (1986). However, for having a better tractability of the models, Phelps and Pollak (1968) proposed a Quasi-hyperbolic discounting rate. But, for Ebert and Prelec (2007) the hyperbolic and quasi-hyperbolic models do not portray the increasing impatience. Hence, they proposed a functional form that presented both the decreasing patience and impatience. In Table 1 the functional forms proposed are shown:

| Model                         | Expression   | Author                        |
|-------------------------------|--|-------------------------------|
| Exponential discounting       | $(1 + \rho)^{-t}$ with $\rho > 0$  | Samuelson (1937)              |
| Quasic-hyperbolic discounting | $\beta\delta^t$ with $0 < \beta, \delta \leq 1$  | Phelps and Pollak (1968)      |
| Proportional discounting      | $(1 + \gamma t)^{-1}$ , with $\gamma > 0$  | Herrnstein (1981)             |
| Power discounting             | $(1 + t)^{-\alpha}$ , with $\alpha > 0$  | Harvey (1986)                 |
| Hyperbolic discounting        | $(1 + \gamma t)^{\frac{-\alpha}{\gamma}}$ , with $\alpha, \gamma > 0$  | Loewenstein and Prelec (1992) |
| Constant sensitivity          | $e^{-at^b}$ , with $a, b > 0$<br>if $b < 1$ , decreasing impatience<br>if $b > 1$ , increasing impatience<br>if $b = 1$ , constant discounting | Ebert and Prelec (2007)       |

Table 1: Discount functions

Regarding what was previously mentioned, there exists a great deal of discussions about the discounting rate of the agents due to its form and the widespread of results from different economic experiments. One of the first discussions to talk about is the fact of considering that the discounting rate of the agents has a hyperbolic or Quasi-hyperbolic form by reflecting people's behavior in relation with the intertemporal consumption (See Ainslie, 1992; Loewenstein and Prelec, 1992; Laibson, 1996, 1998; McAlvanah, 2010<sup>1</sup>; Wang, Rieger, and Hens, 2010; Hurtado Rendón, 2014a). On the other hand, there are some works with few evidences about the form of the Quasi-hyperbolic discounting rate such as those advocated by Carbone (2008) and Abdellaoui, Attema, and Bleichrodt (2010). Now, another element to be discussed is the possibility that socio-demographic variables have any influence on the choice of the discounting rate, or that there may exist a wider correlation of the socio-demographic variables with the discounting rate of the agents. Consequently, there have been a lot of papers that have found out about the previous idea by portraying it with many results, which then made research increase on this. As one of the main problems found, it is how to widespread the results of the experimental economics in regards with the discounting rate.

As an example of what was stated above, we may take the work by Wang, Rieger, and Hens (2010), in which the short and long term discounting rates of an economic experiment

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<sup>1</sup>There is shown a difference in the utility function of the economic profit or loss by dividing the time in intervals. In this way, it is finally concluded that there is a higher subadditivity to the earnings.

done in 45 countries showed big differences in relation to the patience and impatience of the agents. There are plenty of studies in experimental economics that found the differences in the discounting rates were related with features such as age (Wang, Rieger, and Hens, 2010; Green, 1994, Harrison et al., 2002), gender (Ashraf, Karlan, and Yin, 2006, Eckel, Johnson, and Montmarquette, 2005), investment in education (Harrison et al., 2002), caring about little children in families (Bauer and Chytilová, 2009), diversification of activities (Bocquého, Jacquet, and Reynaud, 2013), culture (Wang, Rieger, and Hens, 2010; Hofstede, 1991). Also, the results of those surveys came from different studies on experimental populations such as students or their families (Carbone, 2005, 2008; Abdellaoui, Attema, and Bleichrodt, 2010; McAlvanah, 2010) or their main activities (Harrison et al., 2002; Ashraf, Karlan, and Yin, 2006; Bocquého, Jacquet, and Reynaud, 2013; Bauer and Chytilová, 2009). So, these examples showed the difficulty in the widespread of the results of the experimental economics as for the discounting rate used by the agents to utilize their intertemporal consumptions.

Notwithstanding, Carbone (2005) when carrying out an experiment to 498 participants of The University of Tilburg (Center's family expenditure panel); in which the strategies used by the individuals let the researcher realize if there might exist any relation between the strategies used and their socio-demographic characteristics. Subsequently, it was found a small and systematic influence of the demography on the discounting rate of the agents. Thusly, it was concluded that despite the fact that there were some socio-demographic influences on the discounting rate of the agents, these were lower. In fact, it was finally inferred that what was discovered was a result of great significance in regards to whom the experiments must be done to have then the rest of the population widespread.

However, if it is taken into account what was proposed by Carbone (2005) the results of the economic experiments can be widened in respect to the discounting rate by portraying that the demographic variables have few effects on the choice of the strategies of the experimental

subjects<sup>2</sup>. Nonetheless, the only way to widespread the results obtained from the discounting rate of the agents is by contrasting these results with Quasi-experimental elements. For instance, by using national accounts and making a comparison if the results found are consistent with which has been shown over time by the agents; by taking as a baseline their consumption and income. As a consequence, this previous element is highly used in macroeconomics because of the fact that the macroeconomic models are micro-founded, allowing to overcome one of the great critiques of the experimental economics that states that the subjects behave in a very different way in a laboratory rather than in the real world.

Using variables of national accounts allows achieving the counterpart of the economic experiment, which is the fact of achieving macro-founded microeconomic results. Thus, the use of Bayesian estimation is proposed in this paper by using Dynamic Stochastic General Equilibrium models (DSGE) in order to reach that the results of the economic experiments in regards to the discounting rate be strong and can be easily widespread. By this, this paper is subdivided into four sections. First, a brief introduction to the paper itself is presented. Second, the method used in regards to the explanation of Bayesian estimation is presented; by starting with the proposals of priori probabilities of the parameters using two economic experiments done for Colombia, in which, the short and long term discounting rates were calculated (Wang, Rieger, and Hens (2010) and Hurtado Rendón (2014a)). Afterwards, there will be a presentation of the data to construct the function of posteriori distribution by using the Metropolis Hasting method. In this way, the results depend on the contribution that the data have on the model. In this manner, to reach the robustness on the estimation, two models are used. First, a neoclassic standard model and then a new-Keynesian standard model with price stickiness. Consequently, the short and long term discounting rates for Colombia are shown. Third, the results of the exercises done are portrayed. Finally, some conclusions are given to the paper.

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<sup>2</sup>However, Loewenstein (1999) affirms that the experiments have lower external validity when referring to the capacity of their generalization.

## 2 Our Method

This work is empirical and exploratory for we used the Multiple Triangulation method<sup>3</sup> (Experimental economics, DSGE models and Bayesian approach), and some data in order to look for higher elements in regards with the problem. By this, secondary information<sup>4</sup> is used and complemented by means of experimental research (Wang, Rieger, and Hens, 2010<sup>5</sup> and Hurtado Rendón, 2014a<sup>6</sup>) which was applied to different agents so as to make out the short and long term discounting rates. As a comparison, two models (See Appendix 1, neoclassic and new-Keynesian models) are used to contrast the parameters throughout Bayesian estimation.

### 2.1 Bayesian approach

After estimating the theoretical models adjusted to the Colombian economy, the structural values are calibrated with stationary equilibrium values by adjusting them to long term values. In this way, stationary equilibrium values were used in regards with what has been happening with the Colombian economy. Then, the values of the parameters are estimated by using Bayesian estimation. Later on, it is established the density function a priori by using a beta distribution for the parameters  $\beta$  (Short term discounting rate) and  $\delta$  (Long term discounting rate), because they are found in the domain  $[0, 1]$ . In regards with this, below in Table 2 the parameters proposed are shown:

| <b>Suggested by</b>           | <b>Present bias <math>\beta</math></b> | <b>Long-term discounting factor <math>\delta</math></b> |
|-------------------------------|--|---|
| Wang, Rieger, and Hens (2010) | 0.6                                    | 0.77  |
| Hurtado Rendón (2014a)        | 0.77                                   | 0.89  |

Table 2: Results from economic experiments.

Afterwards, we introduce the data. As the neoclassic model presents a random shock and regarding the New-Keynesian model, two shocks, the data from the Colombian economy of

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<sup>3</sup>According to Cowman (1993), it is the combination of different methods in a study from the same object or event.

<sup>4</sup>DANE, Colombia

<sup>5</sup>Results of the Economic Experiment done to students from Universidad de los Andes (Colombia).

<sup>6</sup>Results of the Economic Experiment done to entrepreneurs from formal and informal sectors in Colombia.

production are used with the first model. And regarding the second model, some data on production and consumption are chosen in order to avoid stochastic singularity problems (See An and Schorfheide, 2005). The priori probability and the likelihood function are combined so as to get to a posteriori probability whose form is:

$$p(\theta/Y^t) = \frac{L(\theta/Y^t)p(\theta)}{P(Y^t)}$$

Where  $\theta$  are the parameters to estimate,  $Y$ : the data and,  $L$ : the likelihood function. Consequently, in order to get closer to the form of the probability, there must be random values of this one by calculating the probabilities of the structural coefficients. Thus, the likelihood function is used to estimate tentative specifications by idealizing that a model  $H_i$  generates the data, and that is not just the fact that the likelihood function in the parameter space is given a priori probability, which was previously generated.

$$p(Y^t/H_i) = \int L(\theta/Y^t, H_i)p(\theta/H_i)d\theta$$

Where  $p(Y^t/H_i)$  is the probability of finding the data under the specification  $H_i$ ,  $L(\theta/Y^t, H_i)$  that represents the likelihood function and  $p(\theta/H_i)$  for a priori distribution under the specification  $H_i$ . Moreover, with the aim of evaluating marginal likelihood of the model in regards with another one, the Bayes factor ( $B_{i,j}$ ) is used and defined by:

$$B_{i,j} = \frac{p(Y^t/H_i)}{p(Y^t/H_j)}$$

If the Bayes factor is higher than one, it is then more plausible the model  $i$  than  $j$  or vice versa. Now, as it is known that the marginal likelihood function is not obtained from a direct way, it might be plausible to take into account what Rabanal and Rubio-Ramírez (2008), stated when talking that values are generated by using the Metropolis-Hastings Algorithm. Subsequently, to obtain this, the Random Walk Metropolis (RWM) variable is used in order to get closer to the form of the function (Griffoli, 2013).

Consequently, in order to obtain the posteriori probability, it is first important to calculate

the likelihood function by considering the observable variables as production and consumption, and the rest of the them as endogenous, but not observable. By this, we obtain the likelihood function that can be measured in vector  $\theta$ , by means of the use of the Kalman Filter (Hamilton, 1994). Afterwards, the mode in the distribution is calculated and then the hessian matrix evaluated in the mode is also calculated. So, the model is calculated and then the Kalman Filter is subsequently used. Then, the posteriori random values are generated by using the Metropolis Hasting Algorithm (Griffoli, 2013). Likely, as this calculation generates a sequence of random values that rely on their past values, in which the new random value  $\theta^{i+1}$ , is accepted with probability  $R$  and not accepted with probability  $(1 - R)$ , we have then that:

$$R = \min\left\{1, \frac{L(\theta^{i+1}/Y^t)p(\theta^{i+1})}{L(\theta^i/Y^t)p(\theta^i)}\right\} \quad (1)$$

Regarding this previous case, a scale was used for the jumping distribution in the Metropolis Hasting Algorithm which was consistent with an acceptance of a 35%<sup>7</sup>. In this manner, if the value  $\theta^i$  is accepted, it is then possible to generate the new random value  $\theta^{i+1} = \theta^i + v^i$  where  $v$  keeps a normal multivariate probability; and if not, it is necessary then to come back to the previous process by means of acceptance or non-acceptance. Taking into consideration this case, 5.000 random draws of the neoclassic model and 10.000 regarding the New-Keynesian model were used.

### 3 Results

First, for the neoclassic standard model, the following a priori distributions (Table 3) were proposed<sup>8</sup>:

| Parameters | Prior mean | std  |
|------------|------------|------|
| $\beta$    | 0.77       | 0.01 |
| $\delta$   | 0.89       | 0.01 |
| $\sigma_c$ | 1.0        | 0.08 |

Table 3: Priors

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<sup>7</sup>As it is suggested, it must be about from 20 to 40 percent.

<sup>8</sup>For  $\sigma_c$  a Gamma distribution was used.

The results obtained after including the data from the posteriori probabilities are found in Figure 1, where gray represents the prior probability, black the posteriori probability and green the mode, also complemented with the data from Table 4.

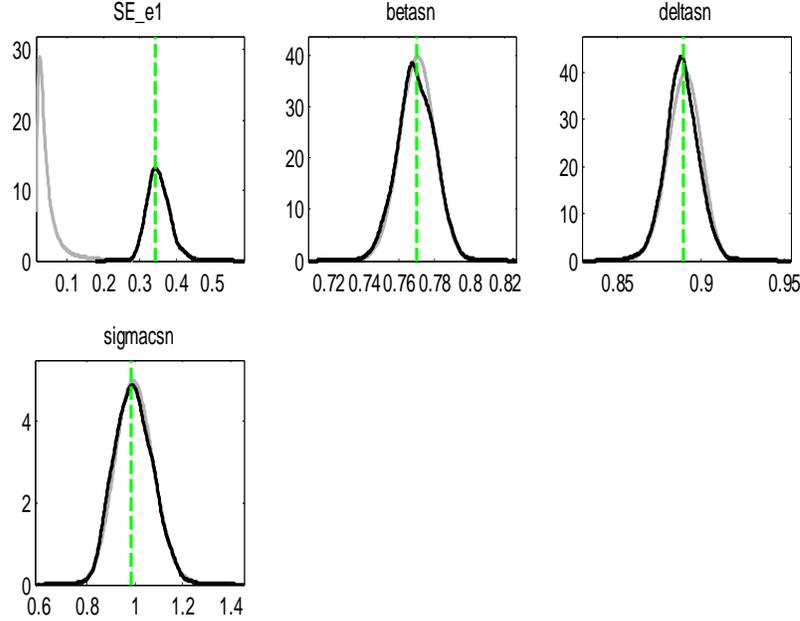


Figure 1: Prior and posteriori

Table:

| Parameters | Prior mean | post. mean | conf. interval (95%) | prior        | pstdev |
|------------|------------|------------|----------------------|--------------|--------|
| $\beta$    | 0.770      | 0.7693     | 0.7533 0.7873        | <i>beta</i>  | 0.0100 |
| $\delta$   | 0.890      | 0.8886     | 0.8731 0.9048        | <i>beta</i>  | 0.0100 |
| $\sigma_c$ | 1.000      | 0.9947     | 0.8684 1.1220        | <i>gamma</i> | 0.0800 |

Table 4: Prior and posterior

When comparing the results of the experiments from Wang, Rieger, and Hens (2010) and Hurtado Rendón (2014a), it was found that the parameters suggested by Hurtado for  $\beta = 0.77$  and,  $\delta = 0.89$  are found in the 95% confidence interval (being the mean posterior  $\beta = 0.7693$  and,  $\delta = 0.8886$ ), showing in this way that the experiments done to entrepreneurs are more consistent with the data from the National accounts than with the ones done to university students. In respect to the parameter of the relative risk aversion  $\sigma_c$ , it can be said that it is in the 95% confidence interval, which according to Laibson (1996) means that the elasticity of intertemporal substitution will be about 1.005 in regards with the mean posterior distribution

owing to the fact that in the Quasi-hyperbolic case there must be only a change for the value  $\sigma_c > 1$ . However, it is now the time to use the second model in order to see if the results present robustness and can be then easily generalized.

Thus, regarding the New-Keynesian model with price stickiness we might have that the priors suggested (Table 5) could be<sup>9</sup>:

| <b>Parameters</b> | <b>Prior mean</b> | <b>std</b> |
|-------------------|-------------------|------------|
| $\beta$           | 0.77              | 0.01       |
| $\delta$          | 0.89              | 0.01       |
| $\sigma_c$        | 1.0               | 0.08       |
| $\epsilon_l$      | 1.57              | 0.05       |
| $\psi$            | 11                | 0.05       |

Table 5: Prior

The results obtained from the Bayesian Estimation exercise are shown both in the following Figure 2 and in the Table 6.

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<sup>9</sup>For  $\sigma_c$ ,  $\epsilon$  and,  $\psi$  Gamma distributions were used.

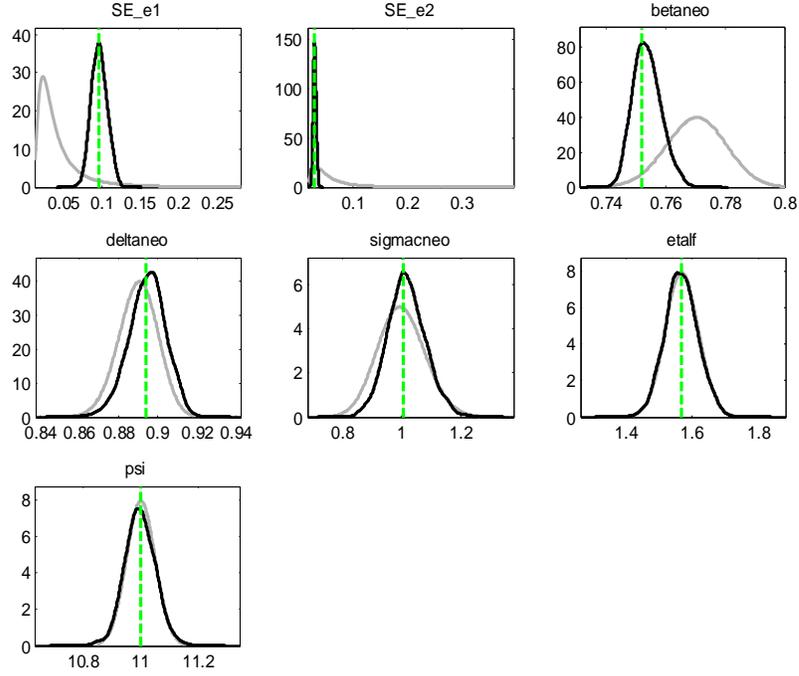


Figure 2: Prior and posteriori

Then, the analytical estimating shows that:

| Parameters | Prior mean | post. mean | conf. interval (95%) |         | prior        | pstdev |
|------------|------------|------------|----------------------|---------|--------------|--------|
| $\beta$    | 0.7700     | 0.7536     | 0.7456               | 0.7605  | <i>beta</i>  | 0.0100 |
| $\delta$   | 0.8900     | 0.8946     | 0.8801               | 0.9103  | <i>beta</i>  | 0.0100 |
| $\sigma_c$ | 1.000      | 1.0165     | 0.9133               | 1.1185  | <i>gamma</i> | 0.0800 |
| $\epsilon$ | 1.5700     | 1.5674     | 1.4830               | 1.6432  | <i>gamma</i> | 0.0500 |
| $\psi$     | 11.000     | 10.9966    | 10.9094              | 11.0798 | <i>gamma</i> | 0.0500 |

Table 6: Prior and posteriori

In this case, regarding a 95% confidence interval, we have that  $\beta$  is outside the interval both in the exercise proposed by Wang, Rieger, and Hens (2010) and in the one by Hurtado Rendón (2014a). Nevertheless,  $\delta = 0.89$  in the case proposed by Hurtado Rendón (2014a) is found into a confidence interval by being this parameter robust in the estimates. According to the data, the long term discounting rate might be then generalized. In this regards, this is a very significant element because if  $\beta = 1$  in the case of a long term hyperbolic discounting rate, an exponential form must be then used, by being this final value the one to be used. Notwithstanding, according

to Laibson (1996), Geraats (2005) and Hurtado Rendón (2014b) the use of the hyperbolic or exponential discounting rate is the first thing that must be defined to carry out any economic experiments, since differences in the simulated models might appear. Consequently, errors might come out while the design of the economic policies, whether there is a wrong specification of the discounting rate of the agents. Besides, in regards with the parameter of relative risk aversion  $\sigma_c$ , this is found into the 95% confidence interval, by which the elasticity of intertemporal substitution will be about 0.99 similar to the previous exercise done. Now, regarding the case of the parameter of the disutility of work, this is found in the confidence interval in the mean posterior distribution 1.57 , and with respect to the profit margin  $\frac{\psi}{(\psi-1)}$  of the companies of intermediate goods that have market power, there would be a margin of about 10%.

## 4 Conclusions

First, the fact that the agents discount under a discounting rate that has the form of a decreasing impatience, it is necessary then to look for a form of widening of the data in order to overcome what was proposed by Loewenstein (1999). In this way, to do this, Carbone (2005) stated that if the socio-demographic variables are not relevant, then the results of the economic experiments might be widespread. However, in a series of studies and economic experiments, it was found that there was great deal of evidence to agree on that the socio-demographic variables are very important when using the discounting rate of the agents. Thus, it is relevant to propose a new solution so as to achieve a bigger widespread of the intertemporal discounting rates. For this, it is presented as a choice, the use of the Bayesian estimation in order to make a comparison of the macroeconomic results with those from the National accounts leading finally to a macro-founded microeconomics.

After contrasting two economic experiments (Wang, Rieger, and Hens (2010) and Hurtado Rendón (2014a)) by means of two DSGE models with Bayesian approach, it was shown that the selection of entrepreneurs in the economic experiments portrayed a better adjustment regarding the data from the Colombian economy. In this manner, it is necessary that the economic experi-

ments that look for defining the short and long term discounting rate of agents, make a contrast with what the data show by using as a baseline, experiments that involve entrepreneurs.

When using two DSGE models with Bayesian estimation, the estimates of the parameters seem to show some evidence in favor of the fact that the long term discounting rate be 0.89 in the Colombian case; which differed from other studies done like the one by Wang, Rieger, and Hens (2010). Nonetheless, for a neo-classic model, the parameters  $\beta = 0.77$  and,  $\delta = 0.89$  are values to be used in the estimates of the DSGE models, when a functional form of a Quasi-hyperbolic discounting rate is incorporated.

As it is known, the method proposed might raise some critiques as long as there is an argument which advocates for the fact that the results are objects to initial calibration. Notwithstanding, the calibration depends on the values of the stationary equilibrium of an economy, and then on the historical data of that economy that might contribute with the construction of the posterior distribution. As a result of this conjunction, there are a posteriori distributions that depend on the contribution of the data to the final distribution. Another element for critique might be also the choice of the priors, since it relies on preconceived beliefs. For this case, objective elements such as the results of the two economic experiments are used. However, it might be admitted that the standard deviation of the priors used subjective elements.

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## Appendix 1

### A.1 The Standard Neo-classical Model

For this, a Neo-classical Standard Model taken from Uhlig (1998) and later on changed to represent a representative agent proposed by Strotz (1956) and Phelps and Pollak (1968).

So, the agent is maximized according to:

$$V_t = E_t \left\{ U(C_t) + \beta \sum_{i=1}^{\infty} \delta^i U(C_{t+i}) \right\}$$

where:

$$U(C_t) = \frac{C_t^{1-\sigma_c} - 1}{1 - \sigma_c}$$

Where  $C_t$  represents the relative consumption of the agents and  $\sigma_c$  the relative risk aversion parameter<sup>10</sup>. In this case, if the parameter  $\beta$  is not equal to 1, it is then different from the exponential model. Like this, the discounting rates vary depending on the comparison time, generating a temporary inconsistency problem; since this is a model used to explain the low saving phenomenon portrayed Ainslie (1992) and Loewenstein and Elster (1992) that considered that these rates bring about self-regulation problems leading to suboptimal levels in the saving rate economic levels due to the fact that future consumptions in comparison with the present, have lower access to the current profit valuation.

In this model, the budget constraint given in real and efficient units of the representative agent will be :

$$C_t + K_t - \frac{(1 - \delta_d) K_{t-1}}{(1 + \pi)(1 + \gamma)} = Y_t$$

Being:  $K_t - \frac{(1 - \delta_d) K_{t-1}}{(1 + \pi)(1 + \gamma)} = I_t$  the inversion of efficient and real units, where  $\delta_d$  represents the capital depreciation rate.

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<sup>10</sup>According to Laibson (1996), in this case, the elasticity of intertemporal substitution will not be  $\frac{1}{\sigma_c}$  anymore.

In this manner, the standardized production given in real and efficient terms will be:

$$Y_t = \lambda_t \left[ \frac{K_{t-1}}{(1 + \pi)(1 + \gamma)} \right]^\alpha$$

where  $Y_t$  represents the production,  $\lambda_t$  the technology,  $K_{t-1}$  the capital,  $\alpha$  the participation of the capital in the production,  $\pi$  and  $\gamma$  the inflation and the rate of the population growth.

Where the technology will be determined by:

$$\lambda_t = \psi \lambda_{t-1} + e_t$$

Being  $e_t$  a white noise and  $0 < \psi < 1$ ,  $\alpha > 0$  y  $0 < \beta, \delta < 1$ , being  $\beta$  the short term intertemporal discounting rate and  $\delta$  the long term intertemporal discounting rate. According to the first-order conditions<sup>11</sup> and assuming that the remuneration of the net capital is in perfect competence conditions, we may have that:

$$\frac{R_t - (1 - \delta_d)}{(1 + \pi)(1 + \gamma)} = \alpha \lambda_t K_{t-1}^{\alpha-1} [(1 + \pi)(1 + \gamma)]^{-\alpha}$$

$$C_t + K_t - \frac{(1 - \delta_d) K_{t-1}}{(1 + \pi)(1 + \gamma)} - \lambda_t \left[ \frac{K_{t-1}}{(1 + \pi)(1 + \gamma)} \right]^\alpha = 0$$

For avoid some critics of Laibson (1996) in the Euler equation will be used the solution proposed for this case, where:

$$R_{t+1} = \alpha \lambda_{t+1} \left[ \frac{K_t}{(1 + \pi)(1 + \gamma)} \right]^{\alpha-1} + (1 - \delta)$$

And the Euler equation in this quasi-hyperbolic world is given by<sup>12</sup>:

$$1 = E_t \left[ \frac{C_t}{C_{t+1}} \right]^{\sigma_c} R_{t+1} \delta [\lambda^* (\beta - 1) + 1]$$

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<sup>11</sup>Transversality conditions are also taken into account (see, Uhlig, 1998).

<sup>12</sup>Where the exponential discounting rate  $\bar{\delta}$  would be equivalent to:  $\bar{\delta} = \delta [\lambda^* (\beta - 1) + 1]$

Being  $\lambda^*$  the unique solution to the non-linear equation (Laibson, 1996, p. 11):

$$\lambda^* = 1 - (\delta R^{1-\sigma_c})^{\frac{1}{\sigma_c}} [\lambda^* (\beta - 1) + 1]^{\frac{1}{\sigma_c}}$$

## A.2 Neo-Keynesian Model with inflation adjustments.

It is used a Standard Neo-Keynesian Model with price stickiness and inflation adjustments by taking into account the model of Calvo (1983) which was consecutively modified by Cúrdia and Woodford (2011) and McCandless (2008).

In this case the representative agent maximizes the utility according to:

$$V_t = E_t \left\{ \sum_{i=0}^{\infty} \beta^i U(C_{t+i}) \right\}$$

where:

$$U(C_t) = \frac{C_t^{1-\sigma_c} - 1}{1-\sigma_c} - \varepsilon n_t$$

Being  $C_t, n_t$  the consumption and the respectively  $\sigma_c$  the relative risk aversion and  $\varepsilon$  the labor disutilities in the function.

In this case, we use the Cash-in-advance constraint given by:

$$P_t C_t = g_t \frac{M_{t-1}}{1+\gamma}$$

The budget constraint of the households is:

$$k_t + \frac{M_t}{P_t} = w_t n_t + r_t \frac{k_{t-1}}{(1+\gamma)} + \frac{(1-\delta_d) k_{t-1}}{(1+\gamma)} - \frac{g_{t-1}}{(1+\gamma)} x + (1-x) g_t$$

The households' income will be:

$$Y_t = w_t n_t + r_t \frac{k_{t-1}}{(1+\gamma)} - \frac{g_{t-1}}{(1+\gamma)} x + (1-x) g_t$$

The budget constraint may be expressed as:

$$k_t + \frac{M_t}{P_t} = Y_t + \frac{(1 - \delta_d) k_{t-1}}{(1 + \gamma)}$$

From the first-order conditions we get that:

$$\frac{1}{w_t} = \frac{\beta E_t(r_{t+1} + (1 - \delta_d))}{w_{t+1} (1 + \gamma)}$$

$$\frac{\varepsilon}{w_t P_t} = \beta E_t \left[ \frac{1}{P_{t+1} C_{t+1}^{\sigma_c}} \right]$$

### A.2.1 The production

The firms have market power, which are exploited by raising prices over the marginal costs. This process is made by dividing the production into two. First, there is one that has to do with the intermediate and differentiated goods. Second, there is another about the final goods in perfect competition; using for its production the intermediate goods. Thusly, the firms of intermediate goods are allowed to change their prices, but not in all periods. For illustration, in each period, a randomly and independent fraction  $1 - \rho$  of intermediate firms may change the prices randomly and independently, and the rest of the firms may adjust them regarding past inflations. This rule is known as staggered pricing. Moreover, given the fact that households receive some profits from the monopolistic competency of the household budget constraints, there comes the term  $ge$  representing the profits that are shared as in dividend payment proportions  $(1 - x)$  in the period  $t$  and the rest in the following period.

### A.2.2 The final goods firms

Supposing that there is a continuum of intermediate indexed firms by  $k \in [0, 1]$  and each firm produces an intermediate good that differs from the rest. The continuum of intermediate goods in the period  $t$ ,  $Y_{t(k)}$ ,  $k \in [0, 1]$ , is bought by the firms of the final goods.

Thus, the production technology of the companies of the final goods will be:

$$\max_{Y_t(k)} \prod = P_t y_t - \int_0^1 P_t(k) y_t(k) dk$$

Subject to:

$$y_t = \left( \int_0^1 y_t(k)^{\frac{\psi-1}{\psi}} dk \right)^{\frac{\psi}{\psi-1}}$$

where

$P_t$  Consumer Price index of the economics.

$Y_t$  Total production.

$P_t(k)$  Product price of the k-th firm.

$Y_t(k)$  Production of the k-th firm.

$\psi$  It is the inverse of elasticity of substitution among the different intermediate goods.

The optimal demand made by the firm of the final goods associated with the firm  $k$  will be:

$$y_t(k) = \left( \frac{P_t}{P_t(k)} \right)^{\psi} y_t$$

So, the level of the prices of the economy for the perfect competency will be:

$$P_t = \left( \int_0^1 P_t(k)^{1-\psi} dk \right)^{\frac{\psi}{1-\psi}}$$

### A.2.3 The intermediate goods Firms

For those firms that cannot achieve optimal prices, the pricing will be based on the inflations from the previous period. Thus, a randomly selected group of proportion  $1 - \rho$  will fix the prices with  $P_t^*(k)$  in the period  $t$ . In regards with proportion  $\rho$ , the prices will be established for the same period according to the following expression<sup>13</sup>:

$$P_t(k) = \frac{P_{t-1}}{P_{t-2}} P_{t-1}(k)$$

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<sup>13</sup>In this respect, it is considered that they come from a log-normal, where  $\pi_t = \frac{P_t}{P_{t-1}}$

With the above equation, the firms that may fix their prices, this will be  $P_t^*$  and for those that may not achieve their prices in the period  $t + n$  they will be then expressed by the following expression:

$$P_{t+n}(k) = \prod_{i=1}^n \frac{P_{t-1+i}}{P_{t-2+i}} P_t^*(k)$$

$$P_{t+n}(k) = \frac{P_{t-1+n}}{P_{t-1}} P_t^*(k)$$

With the previous outcome, we get that:

$$y_{t+i}(k) = \left( \frac{P_{t+i}}{P_{t+i}(k)} \right)^\psi y_{t+i} = \left( \frac{P_{t+i}}{\frac{P_{t-1+i}}{P_{t-1}} P_t^*(k)} \right)^\psi y_{t+i}$$

A  $k$  firm that can select prices will select  $P_t^*(k)$  to maximize:

$$\max_{P_t^*(k)} E_t \sum_{i=0}^{\infty} \beta \delta^i \left[ \frac{P_{t-1+i}}{P_{t-1}} P_t^*(k) y_{t+i} \left( \frac{P_{t+i}}{\frac{P_{t-1+i}}{P_{t-1}} P_t^*(k)} \right)^\psi - P_{t+i} r_{t+i} \frac{k_{t+i-1}}{(1+\gamma)}(k) - P_{t+i} w_{t+i} n_{t+i}(k) \right]$$

where,  $\delta$  represents the long term discounting rate of the agents. Subject to<sup>14</sup>:

$$y_{t+i} \left( \frac{P_{t+i}}{\frac{P_{t-1+i}}{P_{t-1}} P_t^*(k)} \right)^\psi = \lambda_{t+i} \left[ \frac{k_{t+i-1}(k)}{(1+\gamma)} \right]^\alpha [n_{t+i}(k)]^{1-\alpha}$$

Where we can get that the optimal level of prices is:

$$P_t^*(k) = \frac{\psi}{(\psi-1)} \frac{E_t \sum_{i=0}^{\infty} \beta(\delta)^i \left( \frac{P_{t-1+i}}{P_{t-1}} P_{t+i} y_{t+i}(k) \left[ \frac{w_{t+i}}{(1-\alpha)\lambda_{t+i}} \left[ \frac{r_{t+i}(1-\alpha)}{w_{t+i}\alpha} \right]^\alpha \right] \right)}{E_t \sum_{i=0}^{\infty} \beta(\delta)^i (y_{t+i}(k))}$$

The prices will be:

$$P_t^{1-\psi} = \int_0^1 (P_t(k))^{1-\psi} dk$$

$$P_t^{1-\psi} = \int_0^\rho \left( \frac{P_{t-1}}{P_{t-2}} P_{t-1} \right)^{1-\psi} dk + \int_\rho^1 (P_t^*)^{1-\psi} dk$$

$$P_t^{1-\psi} = \rho \left( \frac{P_{t-1}}{P_{t-2}} P_{t-1} \right)^{1-\psi} + (1-\rho) (P_t^*)^{1-\psi}$$

<sup>14</sup>Assuming that:  $Y_{t+i}(k) = \lambda_t (K_{t+i-1}(k))^\alpha (N_{t+i}(k))^{1-\alpha}$

Now, the aggregate factors of the production will have as a basis the equilibrium in which the supply and the demand factors of both capital and labor are the same. From that, we get the following equalities:

$$n_t = \int_0^1 n_t(k) dk$$

$$\frac{k_{t-1}}{(1+\gamma)} = \int_0^1 \frac{k_{t-1}}{(1+\gamma)}(k) dk$$

The expression for labor when having the problem for the intermediate firms is:

$$n_t = \int_0^1 \frac{y_t(k)}{\lambda_t} \left( \frac{(1-\alpha)r_t}{\alpha w_t} \right)^\alpha dk$$

where:

$$n_t = \frac{1}{\lambda_t} \left( \frac{(1-\alpha)r_t}{\alpha w_t} \right)^\alpha \int_0^1 y_t(k) dk$$

The same form:

$$\frac{k_{t-1}}{(1+\gamma)} = \frac{1}{\lambda_t} \left( \frac{(1-\alpha)r_t}{\alpha w_t} \right)^{\alpha-1} \int_0^1 y_t(k) dk$$

Where the optimal economic condition will be determined by:

$$\frac{(1-\alpha)r_t}{\alpha w_t} = \frac{n_t(1+\gamma)}{k_{t-1}}$$

The profits excess is:

$$ge_t = y_t - \frac{w_t}{(1-\alpha)\lambda_t} \left( \frac{(1-\alpha)r_t}{\alpha w_t} \right)^\alpha \int_0^1 y_t(k) dk$$

The productivity is expressed:

$$\lambda_t = \rho_2 \lambda_{t-1} + e_2$$

The growth rate of money would be determined by:

$$g_t = \frac{M_t}{M_{t-1}}$$

Where  $\lambda_t, r_t, w_t, \alpha, g_t, M_t, k_t, y_t$  are the productivity, the returns of the capital, the wage, the share of the capital in the production, the growth rate of the money, the money, the capital and

the production in efficient units.