THE NEUROECONOMICS OF EMOTIONAL CONFLICTS IN MORAL DILEMMA JUDGMENT

A. F. Rocha[1]*, E. Massad[1], F. T. Rocha[1]

1 Medical Informatics, University of São Paulo, Brazil
*armando@enscer.com.br

Abstract:

We are used to think about moral judgment as a predominantly rationally based decision making. But emotion is a key issue on decision-making because it arose in nature as the tool to asses how adequate is animal behavior in adapting the animal to its environment. Neuroeconomics has the purpose to ground economic models in the biological substrate of the brain for decision-making. We used neuroeconomic tools to model experimental results on moral dilemma judgment and voting-decision on firearm control. Our model involves both an *emotional component* and a *cognitive factor* in the estimation of the *expected utility* of conflicting dilemma (voting) propositions. This conflict is the major component determining the decision-making probability. The agreement between our experimental and the theoretical response time distribution seems to validate the proposed model. The EEG activity recorded during dilemma judgment is also in agreement with our theoretical propositions. Our results contribute to make neuroeconomic models predictive and explanatory.

Keywords: **neuroeconomics, moral dilemma, decision-making, EEG, modeling**

Introduction

Emotion is a key issue on decision making because it arose in nature and it was shaped by evolution as the most important tool to assess how adequate is animal behavior in successfully adapting the animal to the environment where it is trying to survive. If action is successful the appraisal is joy, happiness, etc., otherwise the felling must be of pain, displeasure, etc. A supportive environment is agreeable, pleasant, peaceful, etc.; a threatening one inspires anger, fear, panic, etc.

Experimental results on how people experience feelings require two orthogonal dimensions to be explained, what prompted scholars to propose different state spaces to account for their data. For example, in the case of Russel (1980) aroused/not aroused and pleasant/unpleasant were the used dimensions to explain his findings. Rolls (1999) defines emotions in terms of states elicited by positive and negative instrumental reinforces: his dimensions are presentation of reward/punishment and termination of reward/punishment. Rustin and Larsen (1995) used valence dimensions of positive and negative emotions.

One important system to understand the neural organization of emotion is the Seeking system discussed by Pankseep (1998). This system makes animals interested in exploring their word and allows them either to find or anticipate the things they need for surviving, as well as to find or anticipate life-threatening environments or events. Reward and punishment color the activity of the Seeking system. A reward is anything for which an animal will work obtain or to approach. A punishment is anything that an animal will work to escape or avoid (Rolls, 1999). Approaching (liking, accepting, etc.) and avoiding (disliking, rejecting, etc.) are two different, independent and concomitant evaluations, performed by different neural systems (e.g., Berridge, 2003, Graeff, 2004; LeDoux, 1996; Pankseep, 1998) and influencing any decision making about accepting or rejecting a given action **a** as adapatative. One of such evaluation will be called here the expected utility **e(a)** of **a** and the other one will be named the risk **r(a)** of **a.** It is important to stress, that **risk** here is being defined as measure of a possible threaten to survival and not a measure dependent mostly on the uncertainty of an outcome. Conflict **c(a)** on deciding about **a** is a consequence from the concomitant evaluation of **e(a)** and **r(a)** and determines the utility **u(a)** of deciding about **a.**

Stability of individuals as singular entities is dependent on environmental demands. So, environments are classified as *friendly* (inspiring pleasure), *neutral* or *threatening* (inspiring fear) depending on the region occupied by the state point in a Personal Emotional Space (**PES**). The increasing complexity of living in-group demanded the development of the Interpersonal Emotional Space (**IES**). The adequacy of collective actions to promote group survival is assessed in this space. The decision-making dynamics is dependent on **PES** and **IES** because preferences on personal and collective actions are assessed in the corresponding emotional spaces. Conflict may also arise from the simultaneous evaluation of the competitive personal and collective actions in **PES** and **IES**

Greene et al (2001, 2004) studied the conflict created by social-emotional responses and cognitive control in moral dilemma decision-making. Such dilemmas have the following structure:

- a proposition $\mathbf{P_1}$ introduces an social utilitarian action evaluated in **IES**;
- a proposition $\mathbf{P_2}$ describes a personal action evaluated in **PES**, and
- a question **Q** establishes the conflict asking to the individual to decide whether $\mathbf{P_1}$ is appropriate or not in the context introduced by $\mathbf{P_2}$., defining a competition between $\mathbf{P_1}$ and $\mathbf{P_2}$.

Let us consider their examples:

The trolley dilemma: (**P1**) A runaway trolley is headed for five people who will be killed if it proceeds in its present course. (**P2**) The only way to save them is to hit a switch that will turn the trolley onto an alternate set of tracks where it will kill one person instead of five. (**Q**) Is it appropriate to switch tracks?

The foot bridge dilemma: (**P1**) As before, the trolley will kill five people (**P2**) unless you push a stranger to be killed and stop the trolley in order to save the five other people. (**Q**) Is it appropriate to push the stranger?

Brazilians were called on October 23, 2005 for a national referendum about the prohibition of firearm commerce in the country. Voting is mandatory in Brazil and political campaign takes advantage of Radio/TV free propaganda during 40 days before election. Two political alliances arouse in the Brazilian Congress to run the campaign for the **Yes** (for the prohibition of firearm commerce) and **No** (against the prohibition of firearm commerce) voting and defined the themes to compose the media campaign. Advertisements varied in their emotional load. Some advertisements were highly emotionally charged. Examples are: **Yes** advertisement - *A gun in the house may cause a fatal accident killing innocent people, mainly children. You may prevent such events by banning firearm commerce;* **No** advertisement - *People have the right to defend themselves from criminals. To ban firearm commerce hurts you in your personal rights*. Other advertisements were less emotionally charged. Examples are: **Yes** advertisement - *The robbery of firearms from the honest citizen is the main source of guns for the criminals. You may contribute to disarm criminals banning firearm commerce;* **No** advertisement - *To prohibit the firearm commerce will not reduce criminal rates. Voting Yes will not diminish criminality* Political advertisement of both Yes and No campaigns proposed, therefore, vote as a moral dilemma solution, because they had the following structure:

- proposition $\mathbf{P_1}$ provides information about right or wrong use of firearms and
- proposition $\mathbf{P_2}$ states that voting **Yes or No** creates a moral conflict.
- The **Yes** arguments were defined in **IES**, whereas the **No** arguments were defined in **PES**, and
- Conflict arises in deciding or rejecting to Vote **Yes** or **No.**

Neuroeconomics is providing the tools to study the cooperative role between cognition and emotion in decision-making and conflict solving. In this framework, it may be proposed that the utility **u(d)** of a decision-making **d** is a function of the conflict $\mathbf{c(P_1,P_2)}$ established by the arguments $\mathbf{P_1,P_2}$ suporting **d**. Also, it may be assumed that $\mathbf{c(P_1,P_2)}$ is dependent on the expected utility $\mathbf{e(P_i)}$ of each supporting argument $\mathbf{P_i}$. So, we decided to use neuroeconomic tools to study and to model the neurodynamics of descision-making both in a hypothetic framework as in the case of Greene´s approach and in the real context of the Brazilian Election.

Neuroeconomic modeling of decision making

Classical economical theories propose rational decision making about the action **a** to maximize the expected **e(a)** utility of **a** (e.g., Dixit and Skeath, 1999; von Neumann and Morgenstern, 1953) but they have been challenged by many experimental studies disclosing many different violations of its proposals. For instance, human decision makers seem to be torn between the impulse for immediate reward and the awareness that reward maximization is in general achieved in the long run (Glimcher and Rustichine, 2004; McClure et al, 2004). McClure et al, 2004 modeled the discrepancy between short-run and long-run preferences by proposing that the present discounted value of a reward of value u received at delay t is equal to u for $t = 0$ and to $\beta\delta^t u$ for $t > 0$, where $0<\beta\leq 1$ and $0<\delta\leq 1$. Whether β activity is best described as an either/or phenomenon or as part of a smooth discount curve that cannot be detected by current fMRI methods, remains an open question (Ainslie and Moterosso, 2004). Thus, we propose β to be better modeled by a monotonically increasing time function describing the enhancement of **e(a)** as the satisfaction of **n** generating **m** is delayed and we calculate $\mathbf{e(P_i)}$ as

$$\mathbf{e(P_i)} = \beta_i^{1/k_i t}\,\delta_i^{n_i t} \qquad \mathbf{(1)}$$

where β^{kt} models the benefit of $\mathbf{P_i}$ **and** δ^{nt} formalizes discounting of this benefit. Taking into account they dynamics of risk evaluation provided both biology (Graef, 2003) and economics (Kahneman and Tversky,1979; Trepel et al, 2005), we propose the risk $\mathbf{e(P_i)}$ of $\mathbf{P_i}$ to be

$$\mathbf{r(P_i)} = \rho^{kt}\,\delta^{nt} / \rho^{kt}(1 - \rho)^{kt} \qquad \mathbf{(2)}$$

where ρ^{kt} models the risk t of $\mathbf{P_i}$ **and** δ^{nt} formalizes discounting of this risk.

Conflict in decision-making may arise either because $\mathbf{e(P_i),r(P_i) \rightarrow 1}$ during decision about $\mathbf{P_i}$ in **IES** or **PES** as in the case of referendum vote decision, or because $\mathbf{e(P_1), e(P_2)} \rightarrow 1$ where $\mathbf{P_1}$ is an social utilitarian action evaluated in **IES** and is a personal action evaluated in **PES** as in the case of Greene´s dilemma judgment.

In this latter case, conflict ($\mathbf{c(P_1,P_2)}$) is assumed to be dependent on $\mathbf{e(P_1),e(P_2)}$**;** to be maximum if $\mathbf{e(P_1)=e(P_2)}$**,** and to be measured in the closed interval [0,1]. Thus we propose

$$\mathbf{c(P_1,P_2) = -\,(e(P_1) + e(P_2))\,(e_n(P_1)\log_2 e_n(P_1) + e_n(P_2)\log_2 e_n(P_2)),}$$

$$\mathbf{e_n(P_1) = e(P_1)/ (e(P_2)+ e(P_2)); e_n(P_2) = e(P_2)/ (e(P_2)+ e(P_2))} \quad (3)$$

Voting involves as many decisions as the number of candidates or alternative. In the case of the referendum, voting involved decision about supporting (**e(Y)** or **e(N)**) or rejecting (**r(Y)** or **r(N)**) each one of the alternative solutions: voting **Yes** or voting **No**. In this condition, conflict **c(Y), c(N)** about voting **Yes** or **No** is calculated as

$$\mathbf{c(Y) = - (e(Y)) + r(Y)) [e(Y) \log_2 e(Y) + r(Y) \log_2 r(Y)]}$$

$$\mathbf{c(N) = - (e(N)) + r(N))) [e(N) \log_2 e(N)+ r(N) \log_2 r(v(N)]} \quad (4)$$

Conflict increases decision-making difficulty that reaches its maximum (0.5) whenever **$c(P_1,P_2)=1$ ($c(Y) = 1, c(N)=1$)**. Therefore, we calculate the utility **$u(P_1|P_2)$** of deciding about **P_1** given **P_2** as

$$\mathbf{u(P_1|P_2) = (1 – c(P_1,P_2) /2)} \quad (5)$$

assuming it lowest value 0.5 if **$c(P_1,P_2)=1$.** In the same line of reasoning

$$\mathbf{u(Y) = (1 – c(Y) /2), u(N) = (1 – c(N) /2)} \quad (6)$$

We assume that **$u(P_i)>0$** if **$c(P_i)\rightarrow 1$** because a decision has always to be made in order to avoid compromise the efficiency of handling life.

Dilemma solving in the Greene´s hypothetical framework is time constrained by the time the volunteer decided to spend for doing the experiment, although she/he is allowed to take as much time as needed to decide about the adequateness of **P_1** given **P_2**. It is assumed here that the amount of conflict constraints decision-making to a finite time, in order to avoid that difficult problems (**u(D)=0,5**) tie the individual to specific decisions, compromising its ability to efficiently handle his/her life. Hence, the maximum time allocation **T_r** for decision-making is proposed to be

$$\mathbf{T_r(t) = T_r(t-1) – \alpha_1 c} \quad (7)$$

such that decision-making has to occur while it **$T_r(t) > 0$**. Also**,** the accumulated conflict **a(t)** is calculated as

$$\mathbf{a(t) = \alpha_2 a(t-1) + c} \quad (8)$$

such that the probability **$p_t(P_1|P_2)$** of deciding at time **t** about **P_1** given **P_2** is obtained as

$$\mathbf{if\ T_r(t) > 0\ then\ p_t(P_1|P_2) = N (e(D) \times a(t))}$$

otherwise $p_t(P1|P2) = \alpha_3\ p_{t-1}(P1|P2)$ (9)

where α_i are distinct constants and **N** is a normalizing function to keep $\mathbf{p_t(P_1|P_2)}$ in the closed interval [0,1].

Voting decision is less time constrained because the voter may make his mind any time before the Election Day. Because of this we propose

$$v(Y \text{ or } N) = N\ (e(Y \text{ or } No)*u(Y \text{ or } N)) \quad (10)$$

Methods

Experiment 1

The same dilemmas used by Greene et al were presented to the volunteer judgment in a video screen and in the following sequence: 1) **P1** reading – the contents of **P1** was displayed to the volunteer; 2) **P2** reading – the contents of **P2** was displayed to the volunteer; 3) **Q** reading – the question proposing the conflict was displayed to the volunteer and 4) Decision making – the volunteer decided for **P1** or **P2**.

We have used (Foz et al, 2001; Rocha et al, 2004; Rocha, Massad and Pereira Jr., 2004) the correlation entropy (**h(r)**) as a measure of the EEG activity associated to a given emotional-cognitive task. Briefly, the EEG is recorded while the subject is solving the task, e.g. the dilemma judgment. The correlation $\mathbf{r}_{i,j}$ between the EEG activity recorded at the recording sites $\mathbf{s_i,s_j}$ is calculated for all the 20 electrodes of the 10/20 system and for the EEG epochs

a) $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ associated to $\mathbf{P_1}$, $\mathbf{P_2}$ and **Q** reading, in the case of the Greene´s dilemma judgment, or
b) associated to voting (**V**), advertisement evaluations (**E**) and influence assessment (**I**).

The correlation $R_{i,j}$ between the EEG activity recorded at the recording sites r_i,r_j was calculated for all the 20 electrodes of the 10/20 system and for the EEG epochs associated to voting (V), advertisement evaluations (E) and influence assessment (I). The correlation coefficients $R_{i,j}$ were used to calculate what we call *correlation entropy* $h(R_{i,j})$ as

$$h(R_{i,j}) = - R_{i,j} \log_2 R_{i,j} - (1 - R_{i,j}) \log_2 (1 - R_{i,j})$$

which was used for the estimation of the correlation entropy $h(r_i)$ for each recording electrode r_i as

$$h(r_i) = \sum_{j=1}^{20} h(\sim r_i) - h(r_{i,j})$$

with

$$h(\sim r_i) = - \sim r_i \log_2 \sim r_i - (1 - \sim r_i) \log_2 (1 - \sim r_i), \qquad \sim r_i = (\sum_{j=1} r_{i,j}) / 20$$

The $\mathbf{h_V(r_i)}$, $\mathbf{h_E(r_i)}$ and $\mathbf{h_I(r_i)}$ (or $\mathbf{h_{R1}(r_i)}$, $\mathbf{h_{R2}(r_i)}$, calculated for the **V, E** and **I** (or **R1** and **R2**) epochs, respectively, are assumed to measure how much the recorded activity at $\mathbf{r_i}$ is related with the task event **V**, **E** or **I** (or **R1, R2**). Finally, regression analysis discloses the possible relations between $\mathbf{h_V(r_i)}$, $\mathbf{h_E(r_i)}$ or $\mathbf{h_I(r_i)}$ and **v**.

Experiment 2

Brazilians were called on October 23, 2005 for a national referendum about the prohibition of firearm commerce in the country. Voting is mandatory in Brazil and political campaign takes advantage of Radio/TV free propaganda during 40 days before election. Two political alliances arouse in the Brazilian Congress to run the campaign for the **Yes** (for the prohibition of firearm commerce) and **No** (against the prohibition of firearm commerce) voting.

We interviewed 1136 people one week before the referendum asking then to declare their intended vote **v** and if they could change their mind until the Election Day (Table I). In this case, they provided us with a vote second opinion **v**́.

Table I – The Voting Questionnaire

Next week, you have to vote on the referendum about banning the fire arm commerce in the country. ***Select one or more of the following options to best describe your opinion about the banning of the fire arm commerce in Brazil:***	
1. *I will certainly vote Yes (CY),* 2. *I will probably vote Yes (PY),* 3. *Certainly I will not vote Yes (NY),* 4. I have not yet decided my vote (ND), 5. *Certainly I will not vote No (NN).* 6. *I will probably vote NO (PN),* 7. *I will certainly vote No (CN),*	8. *I will certainly vote Yes (CY),* 9. *I will probably vote Yes (PY),* 10. *Certainly I will not vote Yes (NY),* 11. I have not yet decided my vote (ND), 12. *Certainly I will not vote No (NN).* 13. *I will probably vote NO (PN),* *I will certainly vote No (CN),*
First Opinion – Vote v	***Second Opinion – Vote v´***

Results

Experiment 1

Our theoretical predictions seem to be confirmed by the experimental data. Regression between $\mathbf{h(r_i)}$ and $\mathbf{P_1|P_2}$ binary decision ($r = 0.20$ to 0.37, $p<0.00001$) disclosed three types of electrode activity:

a) $\mathbf{P_1}$ electrodes (red/pink areas in Fig. 1A) for which the angular coefficient **b** was greater than **0** ($p<0.05$) meaning that the increasing of $\mathbf{h(r_i)}$ favored the selection of $\mathbf{P_1}$ as appropriate;

b) b) $\mathbf{P_2}$ (or **not-P1**) electrodes (blue/green areas in Fig 1A) for which $\mathbf{b<0}$ ($p<0.05$), that is the increasing of $\mathbf{h(r_i)}$ favored **not** accepting $\mathbf{P_1}$ as appropriate and finally

c) c) **N** (or neutral – yellow areas in Fig. 1A) electrodes for which **b** was not statistically different from zero.

Some electrodes were consistently $\mathbf{P_1}$ or $\mathbf{P_2}$ electrodes whereas some other electrodes were $\mathbf{P_1}$ or $\mathbf{P_2}$ electrodes depending on the EEG epoch ($\mathbf{R_1}$, $\mathbf{R_2}$ or $\mathbf{R_3}$) and type (**ID** or **PD**) of dilemma. The summation $\mathbf{B_2}$ of $\mathbf{b(P_2)}$ computed for the $\mathbf{P_2}$ electrodes was almost twice as large as the summation $\mathbf{B_1}$ of $\mathbf{b(P_1)}$ computed for the $\mathbf{P_1}$ electrodes during $\mathbf{R_2}$; whereas $\mathbf{B_2}$ was almost half of $\mathbf{B_1}$ during $\mathbf{R_3}$. It is interesting to note that the experimental proportion of $\mathbf{P_1/P_2}$ responses was 0,53 and that this values is very close to the values of $\mathbf{B_2/B_1}$ obtained during the reading epochs $\mathbf{R_2}$,$\mathbf{R_3}$. If it is accepted that $\mathbf{e(P_1)}$,$\mathbf{e(P_2)}$ are relative estimations of $\mathbf{P_1}$, $\mathbf{P_2}$ and that the determination of the β_2, β_1, δ_1 and δ_2 values requires the reading of $\mathbf{P_1}$, $\mathbf{P_2}$ and **Q,** then it may be assumed from these experimental results that $\beta_2/\beta_1 \approx \mathbf{B_2/B_1}$ calculated for $\mathbf{R_2}$ or $\mathbf{R_3}$ and $\delta_2/\ \delta_1 \approx \mathbf{B_2/B_1}$ calculated for $\mathbf{R_2}$ or $\mathbf{R_3}$.

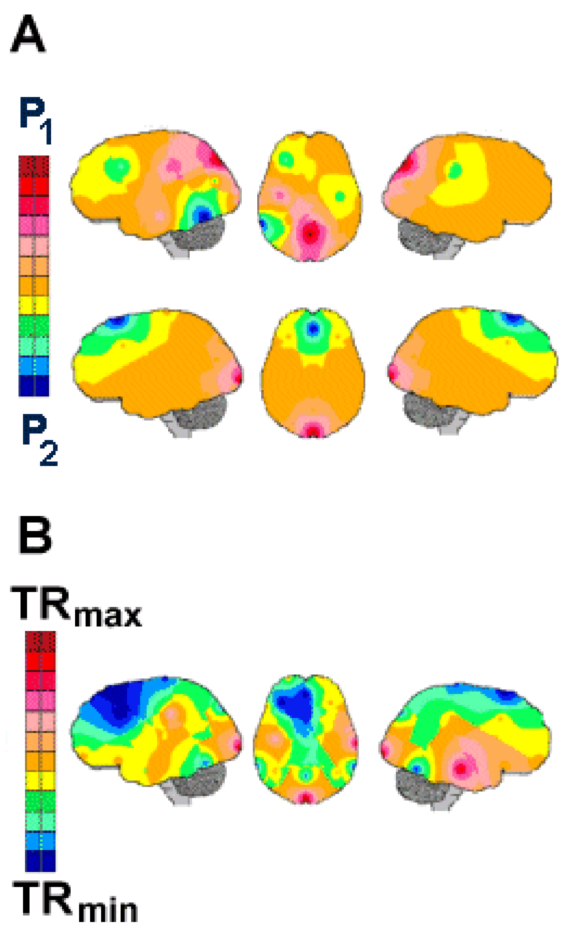

Fig. 1 – Getting theoretical parameters from experimental data

A: a significant correlation between $\mathbf{h(r_i)}$ and $\mathbf{P_1/\ P_2}$ is shown in red if the increase of $\mathbf{h(r_i)}$ was associated with choosing $\mathbf{P_1}$ as appropriate and in green if not-appropriate (or assuming

$\mathbf{P_2}$ as more appropriate). The mappings are those for the reading epochs ($\mathbf{R_2}$ and $\mathbf{R_3}$) of $\mathbf{P_2}$ and **Q** reading, respectively.
B: a significant correlation between $\mathbf{h(r_i)}$ and **ST** is shown in red if $\mathbf{h(r_i)}$ was positively correlated with **ST** and in green if this correlation was negative. The mappings were calculated all reading epochs together.

The mean **ST** was 8.19s for $\mathbf{P_1}$ selections and it was statically different from the mean **ST** value of 5.16 s for $\mathbf{P_2}$ responses. Although **ST** varied considerably, 90% of the decisions were made in the first 12 seconds. The **ST** dynamics was used to adjust parameters $\mathbf{k_1,k_2}$ and $\mathbf{m_1,m_2}$ in eq. 2 in order to keep the dynamics of $\mathbf{e(P_1),e(P_2)}$ within this temporal resolution.

The regression analysis between $\mathbf{h(r_i)}$ and **ST** ($r = 0.49$ to 0.60, $p<0.00001$) also disclosed three types of electrode activity:

a) $\mathbf{ST^+}$ electrodes for which the increase of $\mathbf{h(r_i)}$ was associated with the increase of **ST** (**b>0,** $p<0.05$ - red/pink areas in Fig 1B);
b) b) $\mathbf{ST^-}$ electrodes for which the increase of $\mathbf{h(r_i)}$ was associated with the reduction of **ST** (**b<0,** $p<0.05$ - blue/green areas in Fig 1B), and
c) c) **N** electrodes (yellow areas in Fig.1B) for which **b** was not statistically different from zero.

Most of the electrodes exhibited the same type of activity during $\mathbf{R_1}$**,** $\mathbf{R_2}$**,** and $\mathbf{R_3}$. The summation $\mathbf{B_1}$ of $\mathbf{b(ST^-)}$ for the $\mathbf{ST^-}$ electrodes was around 80% of that of the summation $\mathbf{B_2}$ of $\mathbf{b(ST^+)}$ for the $\mathbf{ST^+}$ electrodes during $\mathbf{R_3}$ (Fig.1B). We assumed that $\mathbf{B_1/B_2}$ could estimate the value of $\mathbf{T_r(0)}$ and that the mean values $\mathbf{B_1^m}$, $\mathbf{B_2^m}$ of $\mathbf{b(ST^-)}$, $\mathbf{b(ST^+)}$ could be estimates of α_1, α_2 respectively. We observed that minors modifications of these estimations of α_1,andα_2 were necessary to obtain the best fit between the theoretical and experimental **ST** distributions (Fig. 2A).

ST distribution for $\mathbf{P_1}$ and $\mathbf{P_2}$ responses is bimodal (Fig. 2B). Although $\mathbf{P_1}$ decisions took longer than $\mathbf{P_2}$ responses, there was no clear temporal differentiation between either early or late $\mathbf{P_1/P_2}$ decisions. This seems to rule out any proposition using the maximum of $\mathbf{e(P_1)}$ or $\mathbf{e(P_2)}$ for deciding about $\mathbf{P_1/P_2}$, because in such a decision most of the early $\mathbf{P_1}$ responses should occur after the moment $\mathbf{T_C}$ for maximum conflict when $\mathbf{e(P_1)=e(P_2)}$ and most of the early $\mathbf{P_2}$ decisions should occur before $\mathbf{T_C}$. As a matter of fact, the experimental $\mathbf{P_1}$ and $\mathbf{P_2}$ temporal evolution were accurately modeled by means of small modifications of β_2**,** β_1**,** δ_1,δ_2**,** α_1 and α_2 (Fig. 2B).

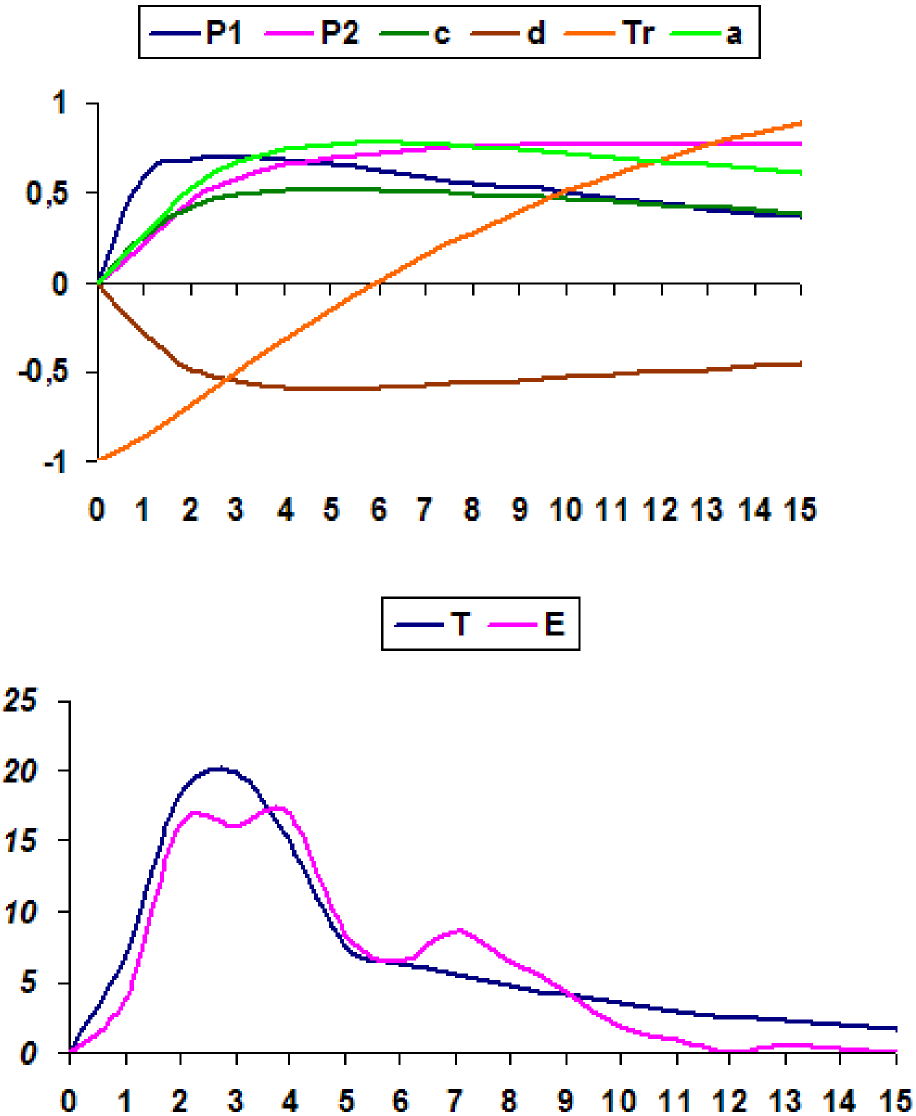

Fig. 2 – Theoretical and experimental data

A: Time evolution of parameters in equations 1, 3,5 7 and 8, with parameters described in table I**.**

B: the experimental (**E**) and theoretical (**T**) **ST** distribution curves

Table I – Simulation parameters for ST distributions

	P_1	P_2
k_1	0.50	0.22
n_1	0.05	0.05
β_1	0.50	0.43
δ_1	0.80	0.85
k_2	0.20	0.15
n_2	0.11	0.08

β_2	**0.90**	**0.83**
δ_2	**0.38**	**0.50**
α_1	**0.30**	**0.30**
α_2	**0.45**	**0.78**
α_3	**0.60**	**0.65**
$T_r(0)$	**0.90**	**0.88**

Parameter values used in **ST** numerical simulations

Voting

Table II shows the probabilities of each type of vote **p(CY)** for **Certanly-Yes** vote; **p(PY)** for **Probably-Yes** vote; **p(NY)** for **Certainly-Not-Yes** vote; etc., for the first (**v**) and second (**v´**)declared vote intention, as well as the probabilities of each type of vote (**v˝**) calculated taking into consideration the possible vote migration **v´** due to people changing mind until the Election Day. Considering only the **Possible&Certain** votes our poll opinion disclosed equilibrium between the **Yes** and **No** votes, similar to that published by the Brazilian pollster Ibope on October 16, because in this case, the probability **p(Y)** of voting **Yes** and **p(N)** of voting **No** calculated from vote **v** in table II are very similar:

p(Y)=p(CY)+p(PY) = 25% + 7%= 32% , p(N)=p(CN)+p(PN) = 26% + 8% = 34% (11)

However, 14% of the volunteers provided a second opinion showing that they could change their mind in the Election Day (vote **v´** in table II). These results are similar to that published by Ibope (2005) in the same week. Taking this into account this possible vote migration, the final voting probabilities **p˝(Y)** and **p˝(N)** would calculated from vote **v˝** in table II is

p˝(Y)=p(CY)+p(PY) = 31% and **p˝(N)=p(CN)+p(PN) = 44%** **(12)**

pointing to the same **No** vote victory that occurred in the Election Day.

TABLE II – POLL DATA

	VOTE		
	v	**v´**	**v˝**
p(CY)	**0,25**	**0,03**	**0,26**
p(PY)	**0,07**	**0,01**	**0,05**
p(NY)	**0,10**	**0,00**	**0,06**
p(ND)	**0,19**	**0,00**	**0,17**
p(NN)	**0,04**	**0,01**	**0,007**
p(PN)	**0,06**	**0,04**	**0,10**
p(CN)	**0,28**	**0,05**	**0,35**
	1,00	**0,14**	**1,00**

Let we consider that **Possible&Certain** votes provide a measure of the vote acceptance **e(Y or N)**, such that:

$$e(Y)) = (p(Y)/ (p(Y)+p(PN)) \text{ and } e(vN) = (p(N)/ (p(Y)+p(PN)) \quad (13)$$

The analysis of the possible vote migration showed that **Certainly-not-Yes** vote migrated to a **No** vote while **Certainly-not-Not** vote migrated to a **Yes** vote. Also, some **Not-Decided** voting was transformed into a **No** vote. The probability **p(NY)** decreased from 10% to 6%, p(**NN)** changed from 6% to 0,7% and **p(ND)** was reduced from 19% to 17%. In this context, let we propose that rejection **r(Y or N)** is dependent on **p(NY), p(NN)** and **p(ND)** such that

$$r(Y) = (p(NY)/ (p(NY)+p(NN)+ p(ND)) \quad \text{and} \quad r(N) = (p(NN)/ (p(NY)+p(PNN)+p(ND)) \quad (14)$$

The acceptance **e(N)** of voting **No** was very similar to that **e(Y)** of voting **Yes** when **v** is considered, but after vote migration, **e(N)** become greater than **e(Y)**. The rejection **r(Y)** of voting **Y** was greater that that **r(N)** of voting **No** even after vote migration. As a matter of fact, while **r(N)** experienced an important reduction, **r(Y)** remained almost the same.

Before the electoral campaign begun in August, 2006; 76% of Brazilians already knew about the referendum and 80% of them declared to vote **Yes** (Datafolha, 2005). Although the campaign did not attract much attention, people started to discuss the referendum with parents (37%) and friends (27%) (Ibope, 2005). As the Election Day approached, Brazilian voters changed mind from an almost certainly **Yes** victory to a land sliding **Yes** defeat. The final result was **No** = 67% versus **Yes** = 33%. The high **Yes** rejection we calculated above from our poll data may explain this large vote migration as the Election Day approached. It is interesting to remark that no one of the Brazilian pollster paid attention to this fact and tried to measure the **Yes** and **No** vote rejection.

We used acceptance and rejection data to calculate **c(Y)**, **c(N)** using equation 4 and equations 6 and 10 to calculate the **Yes**, **No** vote decision probabilities $v_m(Y)$, $v_m(N)$ for both declared intended **v** (Fig. 3A) and the migrated v' (Fig. 3B) voting. In both instances, results forecasting by the modeled voting $v_m(Y)$, $v_m(N)$ (or $v_m'(Y)$, $v_m'(N)$) were better than predicting election results based only on **a(v(Y))** and **a(v(N))**, as usually done by pollster. This method of calculating the final voting super estimates the actual **Yes** voting probability $p_r(Y)$ and underestimates $p_r(N)$ and did not anticipated the land sliding No victory. As a matter, the modeled migrated voting $v_m'(Y)$ **=37%,** $v_m'(N)$ = 63% forecasted with great accuracy the actual results $p_r(Y)$= 33%,$p_r(N)$ = 67%) (Fig. 3B)

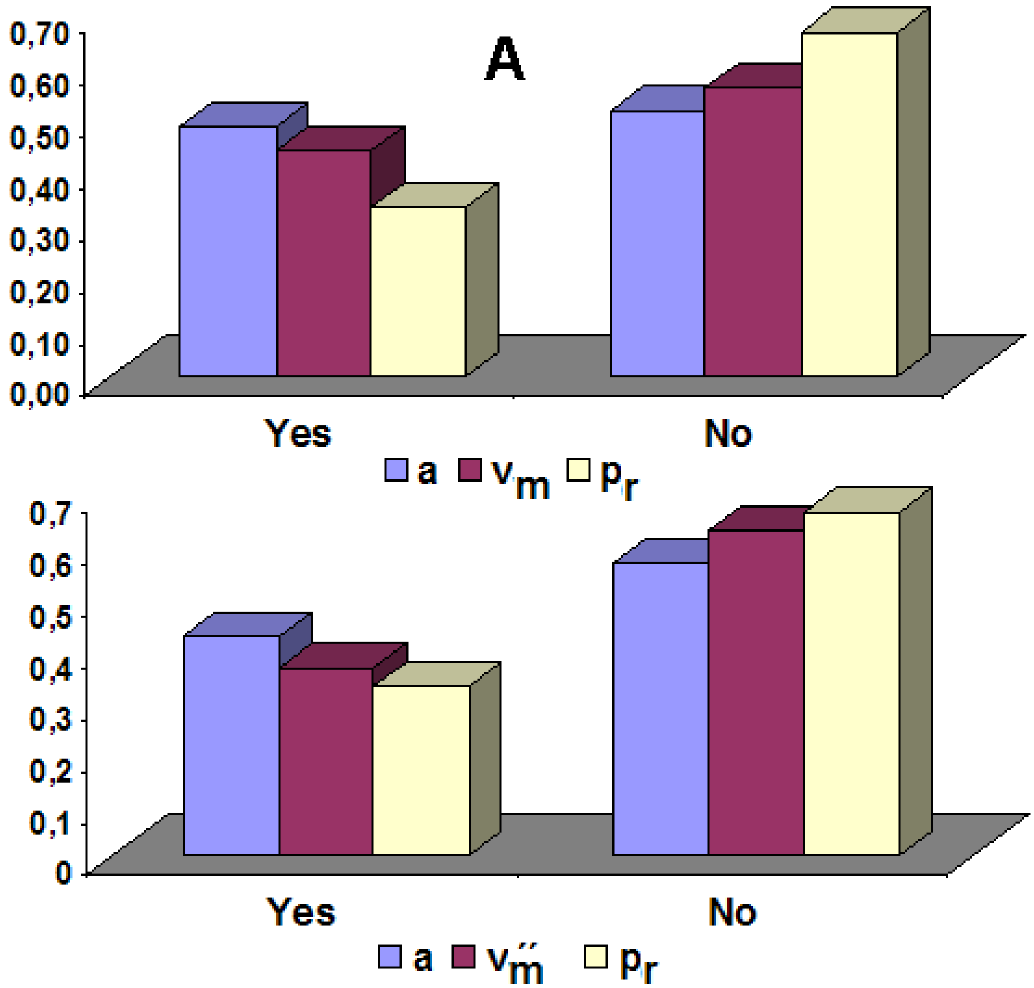

Fig. 3 – Forecasting vote decision

Vote decision forecasting was calculated from the from vote acceptance a (equation 10) and from equations 10-12 and 8 (v_m or v_m'') for both the intended (A) and the migrated (B) voting. The final election results are labeled p_r.

Conclusion

The experimental and simulated results presented here seem to validate our theoretical model as an adequate tool to formalized decision-making in the case of dilemma judgment and voting decision.

The adequacy of the present model to describe our experimental results allows the following properties of the decision-making process:

1) decision-making about any proposition or action is dependent on a dual evaluation concerning the expected reward and punishment ;

2) the expected punishment increases while there is time discounting of the expected reward as the outcome of an action is delayed;

3) the conflict generated by competing alternative actions a_i is dependent on the entropy of their expected reward/punishment $(e(a_i),r(a_i)$;

4) conflict generates anxiety and determines the utility of the decision making, and

5) anxiety speeds up decision-making.

The temporal constraints imposed upon decision-making by anxiety deserve further comments. First, decision-making must be temporally constrained as a consequence of the instability of normal emotional states identified in **PES** and **IES**. Anxiety serves a measure of the difficulty of decision-making that must move the state point from on emotional state defining a motivation m toward a new one evaluating the actions taken to satisfy the necessity triggering m.

References:

Ainslie and J. Moterosso (2004) A maketplace in the brain?, Science, 306:421-423

Dixit, A. and S. Skeath, *Games of Strategy* (W.W. Norton & co, N. York,1999);

Foz, F. B., Luchini; Palmeri, S., Rocha, A. F., Rodela. E. C.; Rondó, A. G., Cardoso, M. B. Ramazzini, P. B.; Leite, C. C. (2001) Language Plasticity Revealed by EEG Mapping. Pediatric Neurology, 26:106-115

Glimcher, P. W. and A. Rustichini (2004) Neuroeconomics: The consilience of brain and decision, Science, 306:447-452

Graeff, F. (2003) Serotonin, the periaqueductal gray and panic. Neuroscie. and Biobehav. Rev. 28: 239-259 (2003).

Greene, J. D., R. B. Sommerville, L. E. Nystrom, J. M. Darley and J. D. Cohen (2001) An fMRI investigation of emotional engagement in moral judgment. Science, 293:2105-2108;

Greene, J. D., L. E. Nystrom, A D. Nystrom, A D. Engel, J. M. Darley and J. D. Cohen (2004) The neural bases of cognitive conflict and control in moral judgement. Neuron, 44:389-400

McClure, S. M., D. I. Laibson, G. Loweestein and J. D. Cohen (2004) Separate neural systems value immediate and delayed monetary rewards. Science, 306:503-507

Rocha, A. F., Massad, E. and Pereira Jr., A. (2004) The Brain: From Fuzzy Arithmetic to Quantum Computing. Springer Verlag, Heildelberg.

Rocha. F.T., A. F. Rocha, E. Massad and R. Menezes (2004) Brain mappings of the arithmetic processing in children and adults. Cognitive Brain Res. 22: 359-372

Trepel, C., C. R. Fox and R. A. Poldrack. Cog. Brain Res, 23:34-50 (2005).

von Neumann, J. and O, Morgenstern, Theory of Games and Economic Behavior (Princeton University Press, Princ